THE PHYSIOLOGICAL EFFECT OF A WATER COOLED HEADDRESS
IN A HEAT STRESS ENVIRONMENT

by 149

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INTRODUCTION

Background

Man has been aware of his survival needs ever since he was conscious of his existence. The response to his climatic environment has been adaptation through habituation coupled to inherent and learned protection and thus he has been able to survive and work in hostile climates, whether hot or cold. Although man appears to have evolved in tropical climates and has in his possession a thermoregulatory system admirably suited for life in warm, dry climates, his behavioral response and his ingenuity to control the micro-climate surrounding his body have been the prime factors contributing toward his survival. Fox (1965) states that these two factors are required for the maintenance of homeothermy and differ at the two environmental extremes; ingenuity plays the major role in the cold environments, while physiology is of major importance in the hot environments. Homeothermy is described by Barbour (1941) as the maintenance of an even temperature in the optimum range for biological activity; for this there must always be a net heat exchange with the environment. Heat is continuously generated by metabolic processes inside the body and in cold environments the heat flow from the body to the environment can be adjusted by increasing or decreasing the insulation between the body and the environment. Insulation in cold environments is provided to a certain extent by the mechanism of vasoconstriction, while in hot environments the process of vasodilatation increases the peripheral blood flow and thus aids cooling through radiation, convection and evaporation. In hot environments the excess heat that can not be dissipated by the thermoregulatory mechanism in the form of radiation, convection, and evaporative cooling must be somehow extracted against the natural heat gradients or remain as stored heat in the body.

Both temperature extremes are hostile to man. As technology advances, the climatic environments where man may desire to live and work become more hostile and his thermoregulatory mechanisms alone can not cope with the load imposed on them. Not only is his system overloaded, but also his mechanisms are disrupted. The purpose of this investigation was to study man's physiological behavior and his regulatory responses in one type of heat stress environment and compare it to his behavior and responses in a comfortable environment.

Heat Stress

Heat stress is defined by Leithead and Lind (1964) as the combination of all those factors which result in heat gains to the body or which prevent the body's heat dissipating mechanisms from working efficiently. A heat stress situation must then be described by the physical variables that act on man in an environment, such as air temperature, humidity, radiant heat sources and air movement. The physiological responses of man as a result of the physical variables in a stress environment can be compared to his basal physiological behavior in a comfortable environment to obtain an indication of thermoregulatory strain.

Heat altered environments can generally be described as being of two types; hot-dry and hot-humid. Thermoregulation to cope with these two types of hot environments depends on different principles. The type of heat stress imposed by hot-dry environments takes the form of large heat gains by convection and radiation which are often readily compensated by evaporation of large quantities of sweat, which threatens homeostasis because of potential dehydration and alterations to the electrolytio balances in the body's liquid volume. In the hot-humid environments heat stress is

due primarily to the restriction imposed by the environment on the evaporation of sweat and the inhibition of heat dissipation gained from metabolism, convection and radiation. The threat can then be assumed to depend on the amount of heat stored in the body and on its effect on disorganizing the control mechanisms. The physiological responses that can be easily and conveniently measured to assess the strain imposed on man when he is exposed to a heat stress situation are: oxygen oonsumption, core temperature, skin temperature, cardiao output, weight loss and subjective sensations of warmth and discomfort.

Winslow and Herrington in their book, "Temperature and Human Life", (1949) reported that:

> "When the upper limits of evaporative regulation are reached, disastrous consequences ensue. With our clothed subjects, profound discomfort was manifest with high relative humidity (70 to 80 per cent) even at atmospheres between 37° and 39° C., and some subjects showed nausea and other subjective symptoms so severe that the experiments had to be discontinued. Under such conditions skin temperatures and rectal temperatures begin to rise sharply and, what is even more serious, metabolism rises also, thus creating a vicious spiral."

It is obvious from the above description that not only disruption, but total disorganization of the thermoregulatory mechanisms occurs when heat storage in excess of the range allowed by the system is reached. The range of complete functional efficiency of the system is, according to Leithead and Lind (1964), exceeded when core temperatures are in excess of 39.5° C. (103° F.). But, the controls of the thermoregulatory mechanisms are not dependent on core temperatures alone. They also depend on skin temperatures. Leithead and Lind (1964) stated that, in order to maintain thermal equilibrium, the skin temperature must be lower than the core temperature. They say that if this relationship is maintained, then the body is capable of transferring adequate quantities of heat from the core to the

skin for dissipation to the environment.

Physiological Responses

Heat stress environments alter the physiological responses of man in various forms. Circulatory activity and the parameters concerned with the transfer of oxygen from the lungs to the muscles are affected by increases in body and skin temperatures. Grollman (1964) states that the circulatory system is a closed tubular system with a relatively constant volume of blood. He indicates that, in the circulation of this constant volume, the following factors are of fundamental importance: heart action (rate and volume), blood pressure, and peripheral resistance. In the circulatory system the outflow of the heart, which is pulsating intermittently at near 100 mm. mercury pressure necessary to overcome peripheral resistance, must equal the inflow to the heart in form of a continuous flow at near negative atmospheric pressure. This balance is very important because when both body and skin temperature rise, vasodilatation occurs in some areas of the body while compensatory vasoconstriction occurs simultaneously in the splanchnic vascular bed to prevent unreasonable decreases in the peripheral resistance of the system. Should the peripheral resistance decrease as a result of vasodilatation, heart action is altered to maintain the necessary pressure in the system by changing the heart rate as well as the stroke volume to provide an increased rate of flow through the system. Eichna, Park, Nelson, Horvath, and Palmes (1950) estimated that, in severe heat, the skin blood flow, as a result of vasodilatation, is between 1 and 2 liters per minute. Therefore, the heart must adjust its basal flow of 4 to 6 liters per minute (Guyton, 1966) in order to maintain the same pressure in the circulatory system.

Williams, Bredell, Wyndham, Strydom, Morrison, Peter, Fleming, and Ward (1962) investigated these adjustments and associated them to oxygen consumption. They found that oxygen consumption, for equal work rates, is significantly lower in a hot than in a comfortable environment. They state that the primary response, to the adjustment required by the circulatory system in the hot environment, is a marked increase in the heart rate in direct proportion to the required metabolic rate. The estimated cardiac output is the same in both the hot and the comfortable environments, but since the heart rate has increased, the stroke volume is lower in the hot environments. Because the large blood flow required by vasodilatation near the skin does not lose much oxygen, the muscles continue to receive near their required oxygen supply even with the lower oxygen consumption. The heart rate is near its maximum and should a necessary acceleration of the beat be required as a result of the muscles demanding more oxygen because of work, the heart is unable to satisfy this emergency demand on the system and collapse occurs.

Indices of Heat Stress

Because of the effects described above, man has always taken an interest on the influence that the environment has on his body. Many attempts have been made to integrate into a single index the effects of two or more of the physical factors that influence heat exchanges between man and his environment. Unfortunately this has not proved easy because of some fundamental difficulties. One difficulty arises from the fact that such an index must be suitable for the most diverse applications. The second difficulty has been in finding a satisfactory measurement that would indicate the effects of heat on man. The final difficulty lies in man

himself and his adaptive and variable nature. However, some of the indices that have been developed will be mentioned and briefly described.

The Effective Temperature Scale was evolved by Houghten and Yaglogiou (1923) and was based on the subjective impressions of groups of individuals to different combinations of air temperature, humidity and air velocity. Dufton (1936) developed the Equivalent Temperature index based on a formula which used air temperature, mean radiant heat, and air velocity effects based on the energy required to maintain thermal balance on a black cylinder which simulated man's thermoregulatory behavior. Winslow, Herrington and Gagge (1937) used the technique of partitional calorimetry to analyse the magnitude of heat flow and to develop coefficients for the heat exchanges through convection, radiation and evaporation. They called their index Operative Temperature and their formula takes into consideration radiant and air temperatures. Robinson, Turrell and Gerking(1945) proposed what they described as physiologically equivalent environmental conditions, obtained by plotting lines of "equal response" using dry- bulb and wet-bulb temperature as coordinates, as a substitute for the Equivalent Temperature scale. Their "response" was an arithmetic sum of the weighed differences in the observed behavior of the heart rate, skin temperature, rectal temperature and weight loss from basal levels. The difference in each physiological index was weighed by the formula

$$\frac{\text{(observation at environment being tested less basal rate)} \times 100}{\text{(observation at most severe environment less basal rate)}}$$

Bedford (1946) proposed the use of the globe thermometer temperature instead of the air temperature in the Effective Temperature (E. T.) scale, and the scale then became known as the Corrected Effective Temperature scale

(C. E. T.). In 1947, McArdle thought that in a hot environment the sweat rate provided a better measurement of the physiological effect than subjective sensations and thus developed the Predicted 4-Hour Sweat Rate (P_4SR) index. This index has been confirmed as a predictor variable for fully acclimatized men, exposed for four hours to a hot environment not so severe as to indicate a P_4SR of about 5.0. Haines and Hatch (1952) adapted the heat balance equation to the assessment of heat stress and this method was further elaborated on by Belding and Hatch (1955) to include a numerical index based on the amount of sweat that has to be evaporated (E_{req}) to maintain thermal equilibrium. Yaglou and Minard (1957) developed the Wet-bulb Globe Temperature (W. B. G. T.) index for the U. S. Armed Forces. It is derived from the Effective Temperature scale. An index similar to the W. B. G. T. was developed by Lind, Hellon, Weiner, Jones and Fraser (1957) and relates tolerance times in saturated and nonsaturated environments. It is called the Wet-bulb - Dry-bulb Index.

Reduction of Heat Stress - Environment

A host of studies on how to allow man to work and survive in heat altered environments have been undertaken and systems to accomplish this purpose have been devised and investigated.

Macro-environment

Systems presently in use to provide man with a comfortable environment are based on artificially providing insulation from radiant sources of heat and by providing capacity for convective and evaporative cooling within his operative range. Since convective cooling is a function of the air velocity and the gradient between skin and air temperatures, when man

is exposed to a hot-humid environment his cooling processes can be aided by increasing the air velocity or by providing a positive gradient between his peripheral temperature and the ambient temperature of the macro-environment surrounding him. Evaporative cooling is a function of the air velocity and the differential vapor pressures between the saturated skin and the air. Large scale air conditioning projects and forced fan ventilation are limited by the difficulty of getting the ventilating or cooled air to where it is needed, the cost of installations and of the power requirements for such large systems. These limitations have thus led to a secondary approach, that of beneficially altering the micro-environment surrounding man.

Micro-environment

The present approach is to provide an insulated artificial micro-environment around the man, which limits radiation and convection gains while providing cooler and dryer air for increased evaporation or conductive heat removal by a medium other than air. Thermal equilibrium is thus achieved by the use of a "cooling suit". There are basically two types of cooling suits in use. Ventilated suits cool man by evaporation and convection and use the rapid expansion of compressed air in a vortex tube to produce cool air that is discharged, on a high flow - low resistance basis, through a multipoint distributing system inside a loose fitting garment. Veghte (1965) reports that this system is ineffective when the garment is constricted, and that it prevents serious heat storage only with sweat losses of significant magnitude. The other type of "cooling suit" is more appropiately called a "full pressure suit" because at all times it must fit tightly over the skin, in order to remove heat by conduction. Veghte (1965) reports that of the various cooling systems evaluated by him under

"moderate" thermal conditions (43° C. with no humidity or radiant sources stated) on resting subjects the water cooled system proved superior to all the others.

When a suit with partial or total coverage of the body is used for conductive cooling, the inherent thermoregulatory mechanisms may be less effective in maintaining internal temperature at the desired range. The problem may be more difficult where metabolic rates vary over a wide range. According to Burriss (1965) the primary approach used to establish comfort conditions for conduction cooling by a suit is to maintain skin temperature within the range bounded on the high side by the onset of active sweating and on the low side by the occurrence of shivering. Conductive body cooling by a suit depresses or lowers the skin temperature on the area in contact with the cooling media. The effect of skin cooling is to constrict subsurface blood vessels and this experimenter surmises that this decreases skin heat conductance rates thus allowing higher internal storage, which in turn requires higher heat removal rates, thus causing a self defeating spiral which requires a high heat removal capacity suit to overcome. Cooling suits, such as the ones described above, can be used in hot-humid conditions but their main disadvantages are bulkiness, which limits movement and requires more effort, and unrealistic power requirements in some conditions. Even with these limitations, investigations on systems designed to cool man's body for the purpose of extending his exposure in altered environments continues.

Reduction of Heat Stress - Body

The third approach to the problem of how, from where and with what to remove excess heat from man so that he can work in hot-humid environments

is to attempt heat removal from the blood stream. It is surmised that a lower blood temperature will allow the thermoregulatory mechanisms to operate within their functional range. This lower temperature may also beneficially alter some of the triggering mechanisms of the thermoregulatory control. In order to study the feasibility of this approach it is important to know what changes occur at subnormal body temperatures in man's physiological behavior and, from this, project possible designs for blood cooling.

Deep Body Cooling

Investigators throughout history have been concerned about the physiological effects of hypothermia when related directly to the treatment of disease. As early as 1772 Robert Boyle suggested that cooling of the body during disease processes might be of benefit. Currie (1798) studied the physiological effects of the immersion of man in cold water. He immersed volunteers in water at 7° C. (44° F.) and measured their oral temperature. He found a slight rise in oral temperature associated with shivering and thus became the first one to discover and report, but not recognize, the internal thermoregulatory process of chemical heat generation through shivering. Pembrey and Hale-White (1896) showed that CO_2 production in bats was lower at lower temperatures; they called this a reduction of metabolism at low temperature. Smith and Fay (1941) cooled and maintained an advanced cancer patient at reduced rectal temperatures of 22° to 32° C. (75° to 90° F.). They suggested that the entire body economy is reduced and stated that circulatory and blood flow are slowed and that the metabolism is reduced by as much as 25 per cent

when deep body hypothermia is maintained. Strangely enough, they stated that as a protection against cooling, shivering onset at 36.1° C. (97° F.) and was sustained until 33.9° C. (93° F.) where it stopped. It is important to mention that most of the work done on cold effects on humans previous to Smith and Fay (1941) studies stated that death occurred at rectal temperatures of 34.4° C. (94° F.) or lower. It is also worthwhile to mention that, in all these studies of deep body hypothermia, the man's head remained outside of the cooling media.

Hypothermia as a medical tool continues to flourish as medical technology progresses. Derkovsky (1965) describes a machine for deep brain hypothermia for the purpose of securing a quick reduction of the temperature of the cortex to 25° C. (87° F.), while at the same time the temperature of the body is kept at 34° to 35° C. (93.2° to 95° F.), by circulating $CaCl_2$ solution at -15° to -18° C. (5° to 1.4° F.) through a helmet fitted to the patient's head. The temperature of the head at the pharyngeal passage is prevented from getting lower than 32° to 33° C. (89.6° to 91.4° F.) by a thermostatically controlled heater. During the first 10-12 minutes the temperature of the cortex can be lowered at a rate of 1 degree C./minute (1.8° F./minute). The objectivo of this cooling process is to decrease oxygen requirements of the brain. This experimenter was not aware of this machine until an abstract was published in "Mechanical Engineering" in December 1966.

Local Cooling

The physiological effects of localized body cooling have also roceived wide attention from many sources. Yoshimura and Iida (1952) have shown that immersion of both legs and feot in ice water for 15 to 20 minutes

daily for one month resulted in a diminution of pain during cooling. This indicates that local acclimatization of the extremities to cold exists and that it may consist largely of vasomotor changes coupled to sensory readaptation. Todd (1944) observed that the rise of blood pressure, during immersion of a hand in water near the freezing point, diminished if the same hand was immersed in cold water on successive days while the subjects were at room temperature. These findings suggest that persistent acclimatization can be induced by localized cooling alone.

Belding (1949) reported that Nova Scotia fishermen, whose hands had been continually exposed to cold, produced no increase in blood pressure during immersion of their hands in cold water--possibly from vasoconstriction not increasing peripheral resistance in the circulatory mechanism because of a lower triggering threshold for this effector response obtained through acclimatization. Glaser and Whittow (1957) studied the physiological effect of immersing one hand in 4° C. (39.2° F.) water for 60 seconds at 60 second intervals for a number of days on six Asians and two Europeans living in Singapore. They found that the rise in blood pressure and heart rate during localized cooling while sitting in a warm environment was significantly diminished and the pain of cooling abolished. They state that this localized acclimatization persisted for intervals of up to 24 hours. They concluded that retained localized acclimatization to cold is due to habituation which also plays an important part in acclimatization to generalized changes in temperature; this manifests central nervous plasticity.

The effects of localized cooling and of lowering internal temperatures artificially have also been studied by those investigatory interested in man's physiological behavior in hot environments. Winslow and Herrington

(1949) reported "vasomotor phenomena" that occurred when an ice bag, covering about 60 cm.^{2}, was applied for 15 minutes to the nape of the neck of subjects that were in what they considered to be a stage of vasodilatation (chest temperature 35.5° C. (96° F.)). They stated that localized chilling had a prolonged progressive influence on the skin temperature of the tip of the index finger of the right hand. They described tho effect of the ice bag in lowering skin temperatures to be similar to those effects produced by local "cold" radiation or drafts.

Benzinger (1959) influenced cutaneous and "internal body" temperatures separately. The "internal body" temperature was measured at theso different locations within the cranium: at the anterior outer wall of the sphenoid sinus, at the anterior ethnoidal region, the vasopharyngeal recess of Rosenmueller and the tympanic membrane. Benzinger's "internal body" temperature was influenced upwards by exercise and downwards by the subject's repeatedly eating an ice water emulsion. Cutaneous temperatures were measured at the forehead, cheek, upper arm, chest, back, lateral thigh, calf, dorsal foot and dorsal hand. Cutaneous temperatures were influenced by varying ambient temperature and humidity. His conclusions will be discussed later, but it must be stated by this experimenter, that it is doubtful that what Benzinger called "internal body" temperature after the ingestion of ice water emulsions was representative of the core temperature. Leithead and Lind (1964) state that oral temperatures are affected, sometimes quite profoundly, by talking, mouth breathing, smoking and eating or drinking for at least 15 minutes after any of those events. Comroe (1966) says that the first rolo in the air conditioning process of air entering the lungs is played by the mucous membranos of tho nose, the mouth and the pharynx; this largo surface has a rich blood supply that warms cold air,

cools hot air and otherwise protects the alveoli under a wide range of conditions. Experimental animals have been exposed to air heated to 500° C. (932° F.) and air cooled to -100° C. (-148° F.); in both instances the trip through the respiratory tract had cooled or warmed the air almost to body temperature by the time it had reached the lower trachea. Rubenstein, Meub, and Eldridge (1960) stated that in their experiments the carotid blood temperature was not affected by breathing cold air or ingesting ice water, but that the application of cold packs at the face and forehead caused a slight lowering of the carotid blood temporature. Because of the facts stated above it appears that Benzinger cooled only the intracraneal tissues and their blood flow without influencing the arterial blood flow into the hypothalamus area. Benzinger (1959) does not indicate any measurement of rectal or core temperature that would indicate deep blood cooling. However, he does state, categorically, that by lowering the "internal" temperature of his subjects he depressed sudomotor activity. He came to the conclusion that it is the combination of two human sensory systems for temperature, and of two complete and independent mechanisms of heat regulation working in concert, that provides man with precision temperature control. These mechanisms are sensory-receptor organs in the skin and in the hypothalamus that have dual control on the effector organs of sudomotor activity in the skin. Guyton (1966) states that stable operation of a control system requires that the receptors exciting the control system detect the factor that is being controlled. In this instance the factor that is being controlled is the <u>internal body temperature</u>.

To summarize, it is probably unwise to conclude that because man possesses thermoregulatory mechanisms apparently well suited for life in warm climates his major threat is that of hypothermia. On the contrary,

it appears that hyperthermia represents a more serious problem than hypothermia since he has evolved a greater capacity for heat-eliminating than for heat-conserving. Because of this it may well be possible to lower his internal temperature by cooling his blood and still receive heat dissipation through evaporation of sweat triggered by the sensor-effector organs in the skin in response to subsurface blood temperature, thus reducing the power requirements of conductive cooling.

PROBLEM

If in a hot-humid environment it is found impractical to attempt air conditioning of either the entire space or the space about the operator, because of restrictions of the task itself or of its location, what can be done for the operator to prevent heat stress and resulting collapse from occurring while extending his stay in the altered environment? As has been stated above, one avenue of research lies in attempting to cool man's blood to maintain his internal temperature within its range of maximum functional ability. What factors must then be considered to select the body location where a cooling device can be worn? What effects are to be expected from its usage; and finally, what physical requirements must it satisfy?

An important consideration, when studying the cooling of man's blood, is where to locate the device in order to obtain the maximum benefit from the body's adaptive capability, its control mechanisms, and the largest blood flow. Guyton (1966) states that the brain, under basal conditions, receives 15% of the total blood flow. The kidneys and the liver combined receive 49%, the inactive muscles 15%, and the skin, heart, bone, glands and other tissues the remaining 21%. When the muscles become active their blood flow increases 20-fold through vasodilatation and an increase

in arterial blood pressure, yet the brain continues to receive an equivalent of the 15% of the basal blood flow. The adjustment of flow to the muscles during exercise is achieved by increasing the cardiac output, by reducing the peripheral pressure and by reducing the flow to the liver and kidneys. The autoregulatory control systems are specially adapted to provide the necessary oxygen to the active muscles and to maintain a near constant cerebral blood flow at all times. Therefore, it is obvious that the head is the external location closest to a large constant blood flow. Not only does the head have a large constant blood flow, but it also possesses some unique characteristics in regard to heat exchanges. Froese and Burton (1957) found that the tissue insulation of the head appears to be constant over a wide range of temperatures. They state that little or no vasoconstriction occurs in the head as a response to cold for the purpose of keeping the brain temperature normal. At lower environmental temperatures a reduction of the circulation to the head would decrease tho supply of blood to the head and consequently of the extra body heat from the missing blood necessary to maintain normal brain temperature. Edwards and Burton (1960) studied the temperature distribution over the surface of the head and drew an isothermal map from their results. The areas of higher temperature on the surface of the head (thus capable of higher heat loss) were the forehead, the scalp and the neck.

When studying the results of previous investigators (Winslow and Herrington (1949) and Webb (1966)) of man's physiological responses in heat altered environments, it is interesting to note that the head has the highest skin temperature recorded in most conditions. This experimenter, in a pilot project, in a comfortable environment (24.4° C. (76° F.) and 50% RH), recorded that immediately after exercise had stopped, the skin temperature

at the head increased to near the level of the rectal temperature and that flushness of the face followed by immediate perspiration occurred. Burriss (1965) describes the head as the area of highest insensible sweat rate in the body (7-11 grams/hour). All these factors seem to point out that there is a very small lag between rectal temperatures and skin temperatures measured at the head. It also appears that the head area has a high capacity for dissipating internal heat through evaporation, and thus insure normal temperature for the brain in hot environments.

Another consideration is what effects will a device designed to cool the blood have on its wearer during and after usage. If it is assumed that this device will be worn around the head, since several factors seem to point out the desirability of this location, then man's habits must be scrutinized. In winter when outside temperatures are below freezing, man will cloth himself very heavily around the body, will wear gloves, but more than likely will go out bareheaded from a comfortable environment into a cold environment. What is the effect of this same individual doing work in the cold environment while wearing heavy clothing? Does he state that it is invigorating and feel that the work is not as heavy even with cumbersome clothing on? Is his thermoregulatory mechanism compensating properly for the temperature gradient between the large portion of the skin that is covered and warm versus the smaller uncovered and cold portion of the head? Should he go indoors immediately, what would be the response to the warmer environment upon entering? Glaser and Whittow (1957) stated that man's adaptation to varying conditions stems from habituation. It is surmised that a cooling device worn on the head would be able to cool man's blood in a hot-humid environment in which his thermoregulatory process is inhibited by the amount of evaporation that the environment allows. It appears

as if the cooling device will not cause any disruptive effects because the situation is similar to that encountered quite often by the body when exposed fully clothed, but bareheaded, to cold environments.

The ideal physical requirements of the device are the following. It should not hinder vision, hearing, breathing nor the ability to communicate orally. It should not be bulky, heavy or uncomfortable. It should allow man to keep both hands free and to be ambulant within a certain range. Its power requirements should be small. It should be low cost and reliable. It should be easy to put on and take off.

The location, constraints and requirements for the device have been stated. To study its potential the problem has to be restated as follows:

> "Can man's blood be cooled by a cooling headdress, and will the headdress allow an increase of man's exposure time to a hot-humid environment, without undue side effects from the manipulation of his thermoregulatory mechanisms?"

METHODS AND RESULTS

Rohles (1965) stated three major factors that must be controlled when doing environmental research with humans. For ease of presentation, these factors and the variables associated with them are presented in Table 1. To attempt to fully control all of these variables would entail enormous disbursements for research. By being aware of them and by using them as guidelines for the researoh, a financially limited incursion into human factors environmental research, such as this one, may be held less suspect.

Table 1. Variables to be considered for human factors research in altered environments. From Rohles (1965).

ORGANIC VARIABLES

- SEX
- AGE
- DIET
- OUTSIDE CLIMATE DURING TEST PERIOD
- BASAL METABOLIC RATE
- PHYSICAL FITNESS AND CONDITIONING
- ACCLIMATIZATION TO ALTERED ENVIRONMENT
- THRESHOLD OF RESPONSES
- PSYCHOLOGICAL
- CIRCADIAN RYTHMICITY

RECIPROCATIVE VARIABLES

- ACTIVITY
  - DURING TEST
  - PREVIOUS TO TEST
- CLOTHING
- EXPOSURE

PHYSICAL VARIABLES

- SOUND
- LIGHT
- INSPIRED AIR
- AIR MOVEMENT
- ATMOSPHERIC PRESSURE
- TEMPERATURE AND HUMIDITY
- MEAN RADIANT TEMPERATURE

Descriptions of Apparatus

Description of the location and capability of where the headdress was tested, of the selection process for the environmental and test conditions and of the equipment, measurements and subjects used in this investigation follows.

Description of Environmental Test Chamber

All the experiments were carried out in the Kansas State University-American Society of Heating, Refrigerating and Air Conditioning Engineers (KSU-ASHRAE) Institute for Environmental Research Test Chamber that has been in operation at Kansas State University since November 1963.

According to Jaax (1967) the chamber consists of two rooms, the test room and the pre-test room. The test room is 3.66 m. wide x 7.32 m. long (12 ft. x 24 ft.) and its ceiling height is adjustable from 2.44 m. to 3.36 m. (8 ft. to 11 ft.). All its interior surfaces are made of aluminum panels. The surface temperature of the panels is controlled by circulating chilled or heated water through copper tubes attached to the back of each panel. The chilled water supply is maintained in a tank cooled by a 15 hp. refrigeration compressor. The hot water supply is heated with steam supplied by the Kansas State University physical plant boilers. A system of mixing valves provides water at the required temperature which is then circulated through the copper tubes in back of the panels. Four independent circuits are available; two for the walls and one each for the ceiling and floor. In this manner surface temperatures of 4.4° C. to 65.5° C. (40° to 150° F.) can be obtained. The panel temperatures are monitored by thermocouples at each panel that sense the water temperature. A composite average temperature for each wall, ceiling and floor is displayed by an

indicating potentiometer and a multipoint recorder.

Conditioned air enters the test room through perforated inlet strips located between panels in the ceiling and leaves at the floor through a continuous slot around the perimeter of the room. An air conditioning system controls the dry-bulb temperature of entering air at any desired level between 4.4° and 65.5° C. (40° and 150° F.). Relative humidities from 10% to 95% can be maintained in the test room by another system consisting of a capillary washer, an absorption dehumidifier, separate fans, ducting and heating and cooling coils. Air velocity measured by room volume changes can be varied from 7.6 to 30.6 cm./sec. (15 to 60 fpm).

Dry-bulb (T_{db}) and wet-bulb (T_{wb}) air temperatures in the test room are measured continuously by a stationary ventilated psychrometer. (See Plate I.) This psychrometer consists of two temperature sensitive elements connected in two basic imbalanced Wheatstone bridge closed circuits. The resistance of these elements has been calibrated for any given temperature between 1.7° and 98.8° C. (35° to 210° F.). One coil is exposed while the other one is surrounded by a wick wetted by capillary action with distilled water. An electric fan suctions ambient air that passes over both elements at a velocity of 4.59 m./sec. (15 ft./sec.). The rate of evaporation of the water from the wick is proportional to the dryness of the air. Both temperatures are recorded independently in the control room by two Brown Indicating Potentiometers on circular charts.

The entire system is controlled automatically from a control room adjacent to the pre-test room by a combination of electronic and pneumatic control equipment. Lights in two graphic control panels indicate what parts of the liquid or air circuits are in operation. In addition to measuring interior surface temperatures and dry-bulb and wet-bulb tempera-

EXPLANATION OF PLATE I

Fig. 1. Stationary ventilated psychrometer for measuring dry-bulb and wet-bulb temperatures in the KSU-ASHRAE Institute for Environmental Research Test Chamber. Note wall jacks for plugging leads of temperature sensors.

PLATE I

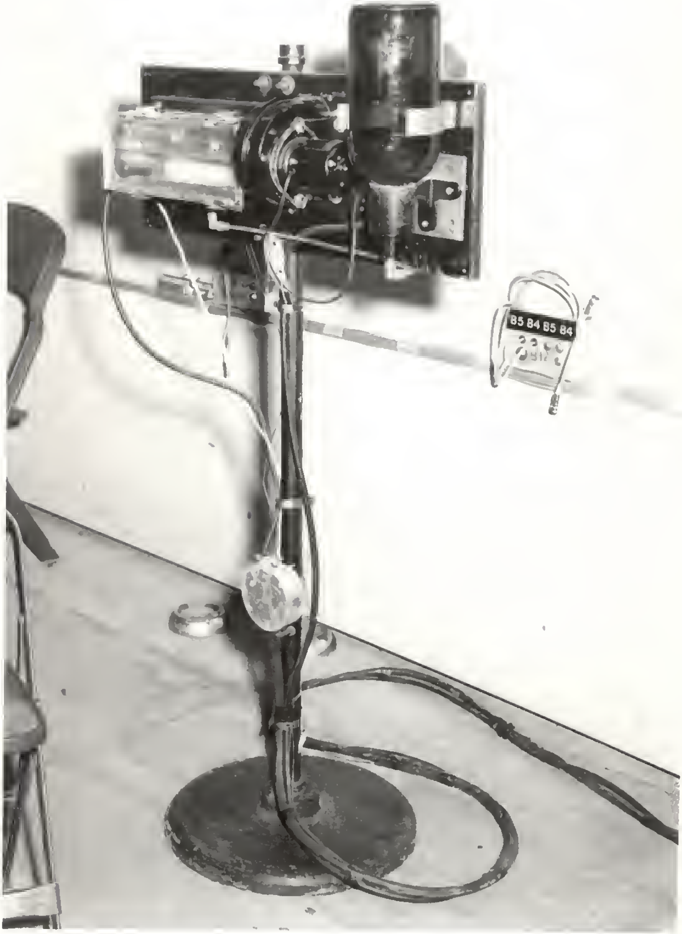

Fig. 1

tures, the test room has eight globe thermometers hanging two feet from the ceiling and located so that each covers an equivalent area of the room.

The pre-tost room is 7.32 m. x 2.74 m. x 2.44 m. (24 ft. x 9 ft. x 8 ft.). It can be air conditioned to any desired comfortable temperature and is equipped with a shower room. An unique feature in both the test room and the pre-test room is that it has wall jacks into which thermistor or rectal probe leads can be "plugged in". Instrumentation for measuring and recording skin temperature and core temperatures is available at the physiological monitoring room located above the control room. In this manner the subject's core and skin temperatures can be monitored before entering, during exposure, and after leaving the test room. A kilogram scale measuring to the nearest 10 grams, which was used to weigh the subjects before and after the tests, was located in the shower room.

Description and Selection of Environmental and Test Conditions

The superb facilities of the KSU-ASHRAE Institute for Environmental Research were available for experimentation to determine the physiological effect of the water cooled headdress. There were questions on how the physiological responses to the headdress would vary between a comfortable condition and a heat stress condition, and on how to determine differences between responses to the environment alone and to the environment when using the headdress.

The ASHRAE Comfort Chart (1963) for air movement of 15 to 25 ft./min. based on data of subjects sitting at rest in light clothing was used to determine what can be called a comfortable condition. According to the chart, at 24.4° C. (76° F.) and 50% RH, 100% of the subjects studied during the summer time felt comfortable. Green (1962) on his Temperature-Humidity

Effects Chart for still air includes this environmontal condition in what he calls the Unimpaired Performance Zone for spacecraft environments where the criterion is heat rejection rates from the body. With theso two sources as references, it was decidcd to use an environmental condition, referred from hereon as "cool condition", consisting of Dry-bulb Temperature ($T_{A_{db}}$) of 24.4° C. (76° F.), with a Wet-bulb Temperature ($T_{A_{wo}}$) of 17.4° C. (63.4° F.), with a resulting Relative Humidity (RH) of 50%, with wall temperatures (T_W) of 31.6° C. (89.1° F.) and air velocity (V) of approximately 25.5 cm./sec. (50 fpm). This air velocity was necessary to change the air in the test room at least 50 times per hour. The wall temperatures were the highest the test room could maintain without undue variability at the specified air temperature and velocity. The selection of this condition as a reference point werved the purpose of indicating the normal physiological responses of the subjects in what is considered a comfortable environment.

The potential utilization of the headdress was considered to be in extending exposure times in hot-humid environments where evaporative regulation necessary to keep the body in thermal equilibrium is inhibited. In order to sclect an environmental condition that would satisfy the term "heat stress" and also allow the experimenter and other personnel to remain in the test room without any undue strain from the intermittent exposure to the condition, various sources were consulted.

Winslow, Herrington and Gagge (1937) suggest that evaporative regulation of the body temperature for nude subjects at rest starts at 31.1° C. (88° F.) Operative Temperature which is equivalent to $T_{A_{db}}$ = 29° C. (84.3° F.), T_W = 33.3° C. (92° F.), and Air Velocity of 15 ft./min., but does not allow for the relative humidity of the ambient. Eichna, Ashe,

Bean and Schelley (1945) charted what they described as Relatively Easy, Difficult and Intolerable conditions for acclimatized men marching nude for four hours at 3 miles per hour at different dry-bulb temperature-humidity combinations. They considered $T_{A_{db}} = 37.8^\circ$ C. (100° F.) and 70% RH as being the upper limit of the Relatively Easy condition and the threshold of the Difficult condition. It must be mentioned that Eichna et al (1945) do not state air velocity for their test conditions. Wyndham (1962) deplores the fact that there is no universally adopted criterion for deciding when a work situation in heat is intolerable, because degree of acclimatization, individual fitness, air velocity and work rates influence these limits. He states that the limiting air conditions for acclimatized Bantu tribesmen doing light mine work is $T_{A_{db}} = 37.8^\circ$ C. (100° F.) and RH = 85%. Again, no mention is made of air velocity. Assuming equal air velocities this combination is considered by Eichna et al (1945) to be "Impossible" and somewhat concurs with Wyndham (1962). Rohles, Nevins and Springer (1966) studied unacclimatized subjects wearing shorts while sitting at rest during a four hour exposure to various dry-bulb temperature humidity combinations in still air and concluded that a 2° F. rise in core temperature was a good index of thermal stress. Because of these studies the KSU-ASHRAE Environmental Test Chamber regulations state that any individual reaching a 2° F. (1.1° C.) rise in core temperature over the basal rectal temperature (BRT) while exposed to hot environments must be immediately removed from the test room into a cooler environment. Rohles et al (1966) placed the combination of $T_{A_{db}} = 37.8^\circ$ C. (100° F.) and RH = 70% in still air as part of the Transition Zone into the Heat Stress Zone for resting subjects.

Based on the above references it was then decided to have the other environmental condition as $T_{A_{db}} = 37.8^\circ$ C. (100° F.), $T_{A_{wb}} = 32.6^\circ$ C.

(90.7° F.), RH = 70%, T_W = 33.3° C. (92° F.) and air velocity at approximately 25.5 cm./sec. (50 fpm). This condition will be referred to from hereon as the "hot condition".

The next criteria to be selected for the experiment were activity rate and exposure time. Physical exercise was considered necessary to influence the internal temperature of the subjects. For severe environmental conditions where test exposure is limited to a 1.1° C. (2° F.) rise in core temperature, activity rate and exposure time are mutually dependent. Therefore, activity rate must be at a level where it does not accelerate this rise and consequently shorten the test exposure sufficiently to render the test useless. This experimenter had earlier undertaken a pilot project that determined that some fit individuals could pedal the bicycle ergometer for 10 minutes during each hour for two hours at a rate of 0.1 hp @ 40 rpm, which is equivalent at 25% efficiency to 4.28 Kcal/min. expenditure for ten minutes every hour during the exposure period. The rest of the exposure time they were to remain seated at rest.

As it was mentioned above, activity level and exposure time must be complementary in severe environments. It has also been mentioned the environmental and test conditions should satisfy the term thermal stress. Rohles' (1966) studies to determine thermal stress conditions for subjects wearing shorts sitting at rest limited exposure time for the 1.1° C. (2° F.) rise in rectal temperature criterion to four hours. McArdle, Dunham, Holling, Ladell, Scott, Thompson and Weiner (1947) empirically devised the Predicted Four Hour Sweat Rate (P_4SR) scale as a heat stress index. This index corresponds to actual sweat rates when fully acclimatized individuals are exposed for a full four hours while sitting in shorts at rest in conditions that are not so severe as to indicate a P_4SR of above 5.0. To have

these references for comparison of test results, test exposures were limited to four hours.

To facilitate comparisons with earlier studies done at the KSU-ASHRAE Institute for Environmental Research the subject's clothing during test exposures would consist of shorts and sneakers. This, of course, did not include the headdress, since the basic purpose of the experiment was to determine the differential physiological effect on the subjects of wearing the headdress in two environmental conditions. Two test conditions, one while wearing the headdress (H) and the other without the headdress (NH), were to be tested in the same environmental conditions (cool or hot).

Description of the Equipment

The equipment used for stationary exercise to simulate a constant work load and to measure and record physiological responses to the test environments is described in the following section. The Bicycle Ergometer, the Gasometer and the Water Cooled Headdress System were located in the test room. (See Plate II.) The subjeot was outfitted with the rectal probe and skin sensors in the pre-test room. The X-Y plotter, Digital Thermometer, printer and other instrumentation were located in the physiological monitoring room. An intercom system provided communication between the test room, pre-test room and physiological monitoring room.

Bicycle Ergometer. The bicycle ergometer used in these experiments was built by the Mechanical Engineering Department of Kansas State University. Resistance to the subject's effort was provided by a balanced aluminum diso acting as a solid armature rotating between the magnetic field of two sets of facing eleotromagnets placed on a pivoting arm. The arm on which the four eleotromagnets were placed pivoted around the axle of the

EXPLANATION OF PLATE II

Fig. 2. View of Environmental Test Chamber during a test in the Cool Environmental Condition showing the two subjects and the test equipment. One subject is breathing oxygen while sitting during recovery on the Bicycle Ergometer. The other subject is at rest wearing the water cooled headdress. Note location of skin temperature sensors.

PLATE II

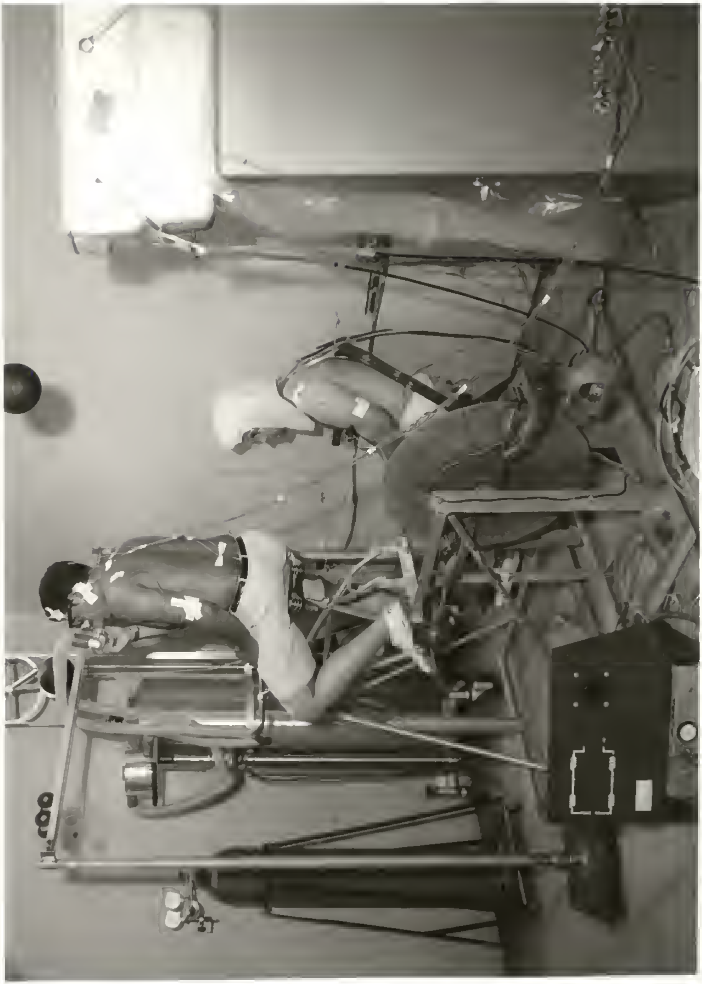

Fig. 2

disc. This arm was 37.5 cm. (1.23 ft.) long and extended out toward the rear. At its end a container for adding weights needed to increase the torque was suspended.

The torque, to be overcome by the effort of the subject, is a function of the speed at which the armature rotates. The braking power can thus be varied by changing the magnetic field, the weight to be balanced on the torque arm or by changing the speed of rotation of the armature. The speed of rotation was kept constant by having the subject pedal at 40 rpm. The clicks of a metronome set at 80 beats per minute indicated to the subject whether or not he was pedalling at the correct pace. Friction losses due to armature bearings and the chain linkage to the pedals was considered a friction torque and assigned the value of 0.069 Kg-m (.5 ft.-lb.) The field current required for the electric dynamometer to balance the torque load on the braking arm was adjustable. The following calculation was used to determine the weight required, including that of the container, for the load to be 0.1 hp @ 40 rpm.

Brake arm = radius = 1.23 ft.

Friction torque = 0.5 ft.-lb.

required hp rate = 0.1 = 0.1 x 33000 = 3300 ft.-lb. @ 40 rpm

$$T + 0.5 = \frac{3300}{2 \times \pi \times 40} = 13.15 \text{ ft.-lb.}$$

$$\text{Torque @ brake} = \text{Torque}\left(\frac{\text{Sprocket teeth in drive}}{\text{Sprocket teeth in multiplier}}\right)$$

$$= 12.65 \times 20/48 = 5.27 \text{ ft.-lb.}$$

Torque = Force x Radius

F = 5.27/1.23 = 4.28 lb. = 4 lb. 4.5 oz. = 1.94 kg.

This was the weight, including that of the container, that was suspended from the torque arm during the tests. This amount was weighed on a calibrated Toledo Speedwright balance. The load that the subject had to overcome when pedalling at 40 rpm was then 0.1 hp.

Gasometer. A Warren E. Collins Chain Compensated Closed Circuit gasometer Model P-1700 was used to measure the subject's metabolism during the periods of rest, work and recovery. This type of gasometer has an oxygen tank of 120 liter capacity suspended in water. A thermometer that is read from the outside measures the temperature of the oxygen in the tank. The water acts as a seal to prevent the oxygen from escaping. The weight of the tank is counterbalanced by a weight, suspended by a chain that passes over a pulley, and by the weight of the chain itself. This chain has a floating pointer which indicates the equivalent volume of oxygen remaining in the tank on a linear millimetric scale on the side of the tank. The pulley actuates a rheostat with its rotation. Any decrease or increase in the volume of the tank such as the changes from the subject's inhaling or exhaling causes a downward or upward movement of the container. When the volume decreases, as a result of the volume of oxygen consumed by the subject, the tank sinks lower into the water. The changes in resistance indicated by the rheostat are recorded by a Houston Omnigraphic, Model HR 95, X-Y Plotter, located in the physiological monitoring room.

The gasometer is of the "closed circuit" type. Through one 3.8 cm. I.D. hose oxygen flows to the subject. Through another 3.8 cm. I.D. hose the subject's exhaled gases return to it. One-way valves, that direct the flow of both the oxygen and the exhaled gases, are located at the mouthpiece. The exhaled gases are a mixture of oxygen, CO_2, CO and water vapor. The return hose is oonneoted to a filter containing a compound with the

trade name of Barylime, which filters the exhaled gases before they reenter the tank. The Barylime chemically reacts with the exhaled CO_2 gas, most of the water vapor usually condensates in the return hose and stays trapped there as moisture. Care was exercised to operate only within certain limits of the tank volume in order to avoid a dangerous concentration of CO inside the tank. This CO buildup was also avoided by flushing the tank after every other usage and controlled by analysing nightly the remaining contents of the tank once the tests were over.

The subjects breathed through a mouthpiece of soft rubber. They were instructed to clamp their noses with a noseclamp. They were to fully exhale before inserting the mouthpiece, which at that time already had a positive pressure. These measures prevented atmospheric air and nitrogen wastes from entering the system and altering its contents and assumedly eliminated dead space in the system. At fixed intervals through the rest, work and recovery periods the oxygen temperature and the millimetric scale on the side of the tank were visually read by the gasometer operator and this information was broadcasted through the intercom system to the X-Y Plotter operator who recorded it on the chart at the precise moment that he had been advised that the readings had been observed.

<u>YSI Rectal Probe</u>. The Yellow Springs Model 401 (see Plate III) rectal probe was used to measure core temperatures. This is a flexible precision thermistor or temperature transducer about 2.38 mm. (3/32") O.D. which was inserted into the subject's anal canal to the depth of six inches (15 cm.). Readings of core temperature at desired time intervals are possible with this probe.

<u>YSI Thermistors</u>. The Yellow Springs Model 409 thermistors were used to measure skin temperatures. These thermistors have a sensitive area

EXPLANATION OF PLATE III

Fig. 3. Yellow Springs Instrument Company, Model 401, Rectal Probe used to measure core temperatures.

PLATE III

Fig. 3

9.5 mm. (3/8") in diameter, 1.6 mm. (1/16") thickness with ceramic insulation on one face only. They were taped on the skin of the subjects. Care was exercised so that they were not placed too tightly on the skin and that they were fully covered by the adhesive tape. The first was to prevent the readings from being influenced by the blood stream temperatures. The second was to prevent the environmental temperature from influencing the readings.

Thermometer and Recording System. The KSU-ASHRAE Environmental Research Institute test room and pre-test room are equipped with numbered walljacks with extension leads to the physiological monitoring room. The thermistor leads from a subject were "plugged in" in previously designated numbered walljacks leading to a 12 position selector switch. The selector switch is connected to a United Systems Corporation Digital Thermometer, Model 500, with a range of 15° to 50° C. (59° to 122° F.) which integrates the temperatures and provides an instantaneous visual display to the nearest 0.1° F. A United Systems Corporation Digitec Recorder prints the information from the digital thermometer in a four digit column. The sensor number was entered into the printer by a United Systems Corporation Manual Identification Unit Model 651. Thus, the output of this system was composed of a paper tape printed with two four digit columns. One column gives the sensor number, and the other the temperature registered by the sensor. Every five minutes the time was entered by the operator into the printer through the manual identification unit. This identified the time at which the data was obtained.

Description of the Water Cooled Headdress and Circulating System

The water cooled headdress that was used in this experiment was

conceived, designed and constructed by the experimenter. It covered most of the hoad area of the subject except for his face. (See Plate IV.) The upper part was one i nch above the eyebrow level. The sides came down approximately halfway between the corner of the eyes and the ears to behind the lower jawbone. The lower part, or bib, was above the larynx; it covered the throat to the upper sternum and left the lower jawbone free. It went back over the shoulders to about one inch above the cervix. It fitted tightly over most of the area that it covered except for the top of the head and the lower throat area. The design was very similar to that of the hood of a ski jacket with the addition of the bib part.

The materials used in the construction were medium weight canvas duck, 4.8 mm. (3/16") I.D., 0.8 mm. (1/32") wall thickness polyethelene tubing, contact cement and a 61 cm. (24") separating zipper. Approximately 3.51 m. (11.5 ft.) of tubing with a capacity volume of 62 ml. (3.808 in.^{3}) were glued to each kidney shaped canvas side of the headdress, for a total of 7.02 m. (23 ft.) of tubing on contact with the head area. (See Plate V.) The sides were sewn together at the bib. The zipper, which ran from the forehead over the head to the neck, provided easy access to the sides during construction and ease of installation on the wearer. Ice cooled water circulated independently in each side of the headdress at a velocity of 10.15 cm./sec. The intake and the return tubes for both sides were joined by glass Y's outside of the headdress. A variable head, centrifugal, circulating, stainless steel, electric motor driven pump with .01 hp motor with maximum flow output of 4.5 gpm at 0 psi and maximum pressure of 11 psi at 0 flow, suctioned water through the headdress and discharged it into a covered 61 cm. x 30.5 cm. x 30.5 cm. (24" x 12" x 12") styrofoam reservoir. The reservoir was located at a height above the subject's head

EXPLANATION OF PLATE IV

Fig. 4. Front view of experimenter wearing water cooled headdress.

Fig. 5. Side view of experimenter wearing water cooled headdress.

PLATE IV

Fig. 4

Fig. 5

EXPLANATION OF PLATE V

Fig. 6. View of interior of water cooled headdress showing location of tubing and water intake and exhaust connections.

PLATE V

Fig. 6

and through a bottom discharge it was connected to the headdress hose. Thus, it provided positive pressure to the system. All the connections between reservoir, headdress and pump were of 12.5 mm. (1/2") I.D., 2.4 mm. (3/32") wall thickness yellow rubber tubing.

Ice was to float in the water of the reservoir at all times. A mercury bulb thermometer was in the reservoir and it was read at least every ten minutes. This reading was considered to represent the temperature of the circulating water in the headdress. Excess water was pumped, when required, for 30 seconds into a pitcher at the same discharge level of the reservoir and measured. This measurement was considered to indicate the circulating capacity of the system.

The composite effect of the system was that it circulated for the cool condition an average of 1.076 liters per minute with a range from 1.064 liters to 1.084 liters per minute at an average temperature of 9.2° C. (48.5° F.) with a range from 7° to 13° C. (44.6° to 55.4° F.). For the hot condition it circulated an average of 1.150 liters per minute with a range from 1.070 liters to 1.205 liters per minute at an average temperature of 11.8° C. (53.3° F.) with a range from 7° to 17° C. (44.6° to 62.6° F.). This flow insured that the water volume inside the cooling coils of the headdress changed approximately 10 times per minute.

The headdress and the cooling system were relatively crude. There were innumerable heat losses in the system because it lacked proper insulation due to poor selection or unavailability of materials. It was very difficult to control the ice level in the reservoir during the hot condition primarily because of the inhibition of rationalization imposed on the experimenter by the hot condition.

Description of Measurements

The physiological variables measured at rest, work and recovery to determine the physiological strain on the subject due to the test conditions were Heart Rate, Oxygen Consumption, Core Tmeperature, Skin Temperature, Head Temperature and Weight Loss. These various indices have been used by most of the experimenters in this field as satisfactory indicators of physiological stress. A doscription of how, where, when and the accuracy of the measurements follows.

Heart Rate. A registered nurse was present in the test room at all times. Her chief duty was to count the subject's pulse every five minutes. She manually palpated the radial artery at the wrist for 15 seconds. (See Plate VI.) She multiplied her count by four and called out the beats per minute. The accuracy of this procedure is considered to be plus or minus 4 beats per minute.

During the test in the hot condition she called out the actual 15 second count and then her calculation. The experimenter also calculated the beats per minute and the matched number was recorded. This procedure prevented arithmetical mistakes that could have been provoked by the exposure of the nurse to the hot environment. This procedure did not prevent judgement errors on her part.

It had been observed by the experimenter in a pilot project and by Morris (1964) that the pulse rate rose rapidly after work was stopped and then followed the normal exponential rate of decline. Therefore, at the end of the work period two extra pulse readings were taken. One was 30 seconds before and the other 30 seconds after the subject stopped work. The extra readings were to check on the decline of heart rate immediately following stopping of work.

EXPLANATION OF PLATE VI

Fig. 7. View of the Environmental Test Chamber during the cool condition. Registered nurse is palpating radial artery of subject for the purpose of measuring heart rate.

PLATE VI

Fig. 7

For one-half hour before and after exposure to test conditions the heart rate was monitored to check on equilibrium and return to normal rates.

Oxygen Consumption. This index was measured by means of the Warren E. Collins Corporation chain compensated gasometer. The volume decrease in the tank over time (Volume/Time) was recorded on graph paper by the Houston Omnigraphic Corporation Model HR 95 X-Y Plotter. These graphs show the volume decrease during the rest, work, and recovery periods.

The subjects sat on the bicycle ergometer at rest for nine minutes prior to the work period. During the latter five minutes of this rest period they were breathing oxygen. They worked by pedalling the bicycle ergometer for a period of ten minutes, during which time they were breathing oxygen. After they stopped work, they remained seated on the bicycle ergometer for 11 minutes while recovering from the exercise. During the first six minutes of this recovery period they breathed oxygen. To summarize, each subject sat on the bicycle ergometer for a 30 minute period, of which he was breathing oxygen for approximately 21 minutes. These 21 minutes were broken down into a rest period lasting 5 minutes, a work period lasting 10 minutes, and a recovery period lasting 6 minutes. All the oxygen consumption calculations are based on the above breakdown. During the remaining 30 minutes of a test condition the subject sat at rest on a chair.

The following calculations are necessary to obtain the net oxygen consumption at Standard Temperature and Pressure (0° C. and 760 mm. Hg) attributable to the work load from the Volume/Time X-Y plotter graphs. (See Fig. 8.) The chain compensated gasometer has a relationship of 133.2 cubic centimeters of volume in the tank for each millimeter of vertical displacement of the tank. By reading the pointer on the milli-

EXPLANATION OF PLATE VII

Fig. 8. Volume/Time curve obtained from X-Y recorder plot during a work cycle in the Cool Condition.

Fig. 9. Oxygen Consumption Curve, calculated from Volume/Time curve in Fig. 8, showing Lag and Build Up areas during a work cycle in the Cool Condition.

PLATE VII

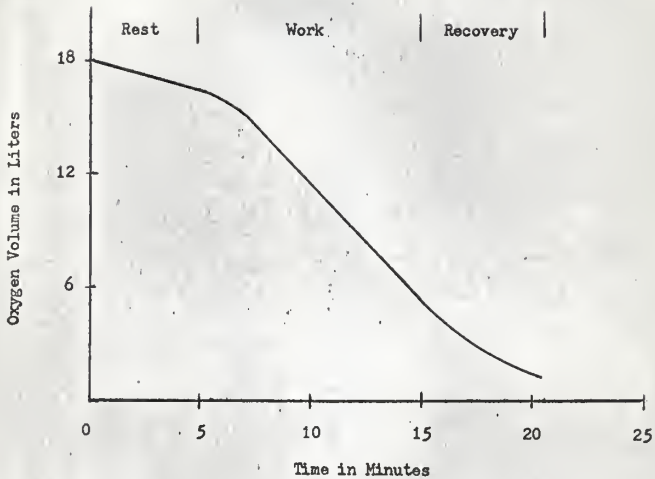

Fig. 8

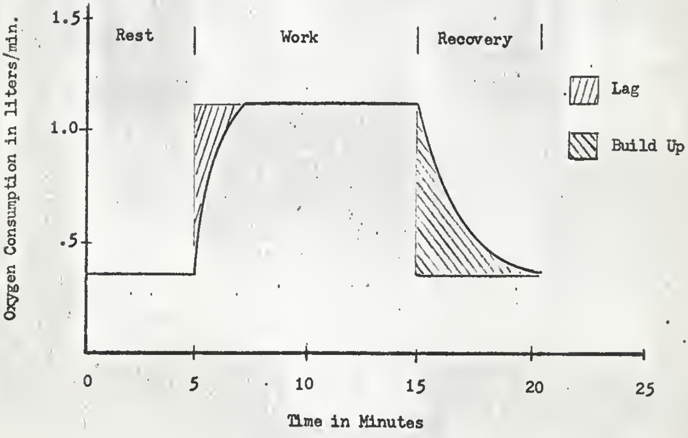

Fig. 9

metric scale attached to the side of the tank the actual volume in the tank can be calculated at any time.

Before the subject started to breath oxygen, a known volume of the gas was introduced into the tank. The limits that this known volume of oxygen sets on the Y-axis of the recorder established a relationship between the tank vertical displacement in mm. and the Y scale of the recorder in inches. This relationship will be referred to here as total displacement over scale (TD (mm.)/S (in.)). The recorder's pen travels at a constant rate on the X-axis over time, consequently the pen plots a line showing the oxygen remaining in the tank over a period of time. When the subject is breathing oxygen from the tank this line consists of a series of up and down oscillations of various vertical heights. These oscillations represent the inhalations (down) and exhalations (up) of the subject. As oxygen is consumed by the subject the volume of the tank is reduced and the pen does not return to the same height on the Y-scale. The upper part of the trace then represents the remaining volume of the tank.

During the rest period the rate of consumption is relatively constant, but during the start of the work period a "lag" appears. During the recovery period a "build up" is evident. (See Fig. 9.) Brouha (1960) says that the "lag" represents the time when oxygen delivery to the working muscles fails to meet the demand and energy is released anaerobically. During this "lag" period lactic acid is formed in the muscles and the concentration of lactate in the blood increases. The incidence of a high concentration of lactate in the blood is an evidenco of fatigue. When exercise stops, oxygen is available to reconvert lactic acid into glycogen and a regeneration of pyruvic acid occurs. Oxygen debt is the amount of "lag" and it represents the anaerobic processes required to achieve

performance. The oxygen consumed above the resting level during recovery is the amount of "build up" necessary to repay the debt. Recovery thus depends on both the rate at which the individual reconverts lactate into glycogen and on the amount of anaerobic effort done to achieve performance.

As a check on the linearity of the X-Y plotter at least two tank scale readings and two time readings were manually recorded on the graph during each of the rest, work, or recovery periods by the X-Y plotter operator. Oxygen temperatures and barometric pressure readings were obtained and recorded at least twice during each period.

The actual consumption for a given period is calculated as follows:

(TD (mm.)/S (in.)) x (133.2 cc./mm.) x (Y scale (in.) of graph for each period under consideration) x (Factor for reducing volume of moist gas to equivalent volume at Standard Temperature and Pressure)

The following formula was used to calculate the net oxygen consumption for the work period; or as Karpovich (1965) calls it, the net cost of work done.

$$\left[(\text{Total work } O_2 + \text{Total Recovery } O_2) - (\text{Rest } O_2) \times (\text{Minutes of work} + \text{minutes of recovery})\right] / (\text{Minutes of work})$$

<u>Core Temperature</u>. This index has previously been called rectal temperature or internal body temperature, but recent literature (Leithead and Lind, 1964, and others) refer to it as core temperature (T_c) and for that reason it will be referred to here as such. It was measured to the nearest 0.1° F. by a Yellow Springs Model 401 rectal probe. This flexible

precision thermistor was introduced in the subject's anal canal to the depth of six inches (15 cm.). A wrapping of adhesive tape served to control insertion depth and provided an anchor for the anal sphincter. To avoid accidental tension on the probe the plastic coated thermistor lead was taped to the skin above the cleft of the buttocks.

These probes were calibrated by putting them in hot water together with a calibrated mercury bulb clinical thermometer. Equal readings were displayed over a period of time by the thermistor probe-digital thermometer system and the mercury bulb thermometer. The temperatures at which they were tested ranged from 26.6° C. to 51.6° C. (80° to 125° F.).

Recording of the core temperatures (T_c) was done every five minutes during exposure to test conditions by the United Systems Corporation Digitec Printer. For one-half hour before and after the exposure this index was monitored in the pre-test room to check and obtain the basic core temperature (BCT) and the return to near normal temperature. The basic core temperature (BCT) was considered to be the equilibrium core temperature obtained in the pre-test room prior to entering the test room. The temperatures were identified by entering the sensor number into the printer through the United Systems Corporation Manual Identification Unit.

<u>Skin Temperature</u>. Four Yellow Springs Model 409 thermistors were placed on the subjects to obtain their skin temperature to the nearest 0.1° F. The arithmetic average of the temperatures (T_s) registered by these four sensors is considered in this experiment to be representative of the skin temperature of the subject. Two of these sensors were located on the arms above the tricep brachii muscle. The other two were located on the legs above the quadriceps femoris muscle.

The same calibration and temperature recording procedures as

described for the core temperature were used for these sensors.

Head Temperatures. Five Yellow Springs Model 409 thermistors were placed on the subject's head to obtain his head surface temperature to the nearest 0.1° F. The arithmetic average of these five temperatures is considered representative of the head surface temperature (T_h) of the subject. One sensor was placed on the throat directly above the carotid artery. Two were placed symmetrically behind the ears on skin above the Os Temporale bone. Two more were placed symmetrically on the forehead above the eyebrows, but below the hairline, above the Os Frontale bone. The two sensors on the forehead were outside the headdress; the sensors behind the ears were not in contact with the headdress because they were protected by the ears. The throat sensor was under the headdress, but properly insulated from it.

The same calibration and temperature recording procedures as described for the core temperature were used for these sensors.

Weight Loss. A Fairbanks, Morse & Co. beam balance platform scale calibrated by the State of Kansas Bureau of Weights and Measurements that measured weight in kilograms to the nearest 10 grams was used to weigh the subjects. The subjects were weighed nude before outfitting them with the rectal probe and the sensors previous to the start of the test. Then they were weighed outfitted with the rectal probe and the sensors on, but without clothing. Immediately after leaving the test room they removed their clothing and dried themselves. They were then weighed outfitted with the rectal probe and sensors on. After their core temperature had come down to near the original value recorded before entering the test room (Basic Core Temperature or BCT), the rectal probe and the sensors were removed and they were weighed nude once more. The subjects were instructed to place

their feet over strips of adhesive tape for every weigh-in. The value considered as his weight loss is the difference between the outfitted weights.

Water was available to the subjects on request. It was measured and given to them in 150 cc. quantities. The weight of the water drunk by the subject between weigh-ins was added to the weight loss.

Subjective Sensations. Houghten and Yagloglou (1923) determined the "ASHRAE comfort zone" and verified the Effective Temperature scale within this zone by exposing large groups of subjects to various temperature-humidity combinations. They had the subjects state every hour their subjective sensation of warmth or coolness by using a five point subjective sensation scale. For the purpose of comparison between test conditions and to obtain a subjective measure of the physiological influence of the head-dress, the two subjects in this experiment were asked to state their subjective sensation during each test condition. The same subjective sensation scale used by Houghten and Yagloglou (1923), as shown in Table 2, was used.

Table 2. Subjective sensation scale.

Too Cold
Comfortably Cool
Very Comfortable
Comfortably Warm
Too Warm

Description of the Subjects

Two Kansas State University undergraduate students were paid by the hour to serve as subjects. One (CHA) had worked outdoors for a construction firm during the summer and was believed to possess a high degree of seasonal

acclimatization. The other (BAK) had attended summer school and was considered to have a lower degree of seasonal acclimatization than CHA. They were both highly motivated individuals and tried very hard to make the investigation a success. Table 3 shows their physical characteristics in a tabular form.

Table 3. Physical Characteristics of subjects.

Subject Code	Age yrs.	Height m.	Weight kgs.	DuBois Body Area $m.^2$	Sheldon's Somatype
BAK	23	1.74	86.35	2.02	651 Flabby
CHA	22	1.70	80.26	1.91	342 Athletic

Subject BAK had a very sparse head of hair while CHA had a bountiful growth. The major differences between the subjects were in physical fitness and body build. Both subjects were clothed in cotton shorts and low cut tennis shoes during their exposure to the environmental conditions.

Experimental Phase No. 1 - Method

Because of difficulties encountered during the experimental stage, the experimental design had to be changed after the first four days of testing. These difficulties will be described in detail later. On account of these difficulties the experiment was divided into two phases which for clarity will be referred to as Experimental Phase No. 1 and Experimental Phase No. 2. The description of each experimental phase will cover the experimental design and procedure, the results and the discussion.

Experimental Design and Procedures

It was originally assumed that the physiological effects of the water cooled headdress would be immediate, independent and comparative. By immediate, it is meant that when the headdress was worn by the subject the physiological responses to its cooling capability would occur within a short span of time. By independent it is meant that any carryover effects between test conditions from "with headdress" (H) to "without headdress" (NH) or vice versa would be equal. By comparative it is meant that if in four test conditions of one hour duration, the subject(s) wore the headdress (Test Condition H) for the first and last test, the results of these two test conditions would be similar and comparative. The experimenter was aware of Brouha's (1960) warning that the costs of work and recovery increase with the repetition of work cycles and that this increase becomes greater with more severe environmental conditions, but because it was believed that the headdress would decrease this effect, disregarded it. The variables which were considered to satisfy Rohles' (1965) warning about controlling all possible factors that could affect environmental research on humans are shown in Table 4.

With the above assumptions and with the objective of obtaining as many observations as possible, the experimental design for what is to be referred here as Experimental Phase No. 1 was constructed as follows. It was attempted to balance carryover effects for each of two subjects, between test conditions (H and NH) within an environmental condition, by using two sequences of test oonditions in four equal environmental conditions (cool or hot). One sequence for the test conditions followed the order of H-NH-NH-H, while the other sequence followed the order NH-H-H-NH. to balanoe the total experiment, the Experimental Design was as shown in Table 5.

Table 4. Variables to be considered for human factors research in altered environments and the extent of their control.

Variables	Extent of Control	Max. °F.	Ave. °F.	Min. °F.
OGRANIC VARIABLES				
SEX	Males			
AGE	22-23			
DIET	Not controlled; suggested they have plenty of salt with meals before hot tests.			
OUTSIDE CLIMATE	Week prior to Exp. Phase No. 1	83	69	56
	During Exp. Phase No. 1	70	62	54
	Week prior to Exp. Phase No. 2	72	63	54
	During Exp. Phase No. 2	78	64	50
	RH ranged from 32 to 78% for max. temp. and from 74 to 96% for min. temp.			
METABOLIC RATE	Measured at each test during rest, work and recovery periods.			
PHYSICAL FITNESS AND CONDITIONING	Student subjects, paid hourly wates for their work. CHA good physical condition; BAK fair.			
ACCLIMATIZATION TO ALTERED ENVIRONMENT	Assumed that it would progress throughout the experiment, counterbalancing of this progress provided by experimental design. Although summer heat in Kansas had been experienced by both, seasonal acclimatization was implied to be greater on CHA than on BAK.			
THRESHOLD OF RESPONSES	Observed for both environmental conditions with and without cooling headdress.			
PSYCHOLOGICAL	Not controlled, although alertness was subjectively observed prior and during tost.			
CIRCADIAN RYTHMICITY	Altered to a certain extent by scheduling exposures to test conditions during evening.			

Table 4 (concl.)

Variables	Extent of Control
RECIPROCATIVE VARIABLES	
ACTIVITY	
DURING TEST	Followed set pattern, 10 min. work in each hr.
PREVIOUS TO TEST	One hour in pre-test room for outfitting. Daily activities for at least 8 hours previous to reporting for testing.
CLOTHING	Shorts and sneakers.
EXPOSURE	Objective was 4 hours for both hot and cool environments.
PHYSICAL VARIABLES	
SOUND	Level was constant, same people in test room for each test. (Less than 65 db.)
LIGHT	Same level every day. (Approx. 70 foot candles.)
INSPIRED AIR	Breathed ambient air which had approximately 50 air changes in the room per hour. Measured the oxygen consumption during the work cycles. Breathed oxygen at near ambient temperatures for 21 minutes of every hour.
AIR MOVEMENT	Air circulated in test room @ less than 50 FPM. Increased to near 60 FPM around the subject when pedalling bicycle ergometer.
ATMOSPHERIC PRESSURE	736-738 mm. Hg.
TEMPERATURE AND HUMIDITY	Cool 24.4° C. (76° F.) 52% RH. Hot 37.8° C. (100° F.) 70% RH.
MEAN RADIANT TEMPERATURE	Wall and floor temperatures. Cool 31.7° C. (89.1° F.) Hot 33.4° C. (92.1° F.)

Table 5. Experimental design of Experimental Phase No. 1.

Week	Day	Environmental Condition	Test Condition Sequences - Subjects BAK	CHA
First	Monday	Cool	H NH NH H	NH H H NH
	Tuesday	Hot	NH H H NH	H NH NH H
	Wednesday	Hot	NH H H NH	H NH NH H
	Thursday	Cool	H NH NH H	NH H H NH
Second	Monday	Hot	H NH NH H	NH H H NH
	Tuesday	Cool	NH H H NH	H NH NH H
	Wednesday	Cool	NH H H NH	H NH NH H
	Thursday	Hot	H NH NH H	NH H H NH

Key: H = With Headdress, NH = Without Headdress

The two subjects were exposed to the same environmental conditions at the same time. Table 6 shows the procedure for one subject following the NH-H-H-NH test sequence. The other subject would enter the test room a half-hour after the first. He would follow the H-NH-NH-H test sequence and would work while the first subject rested. There were two headdresses available, one for each subject. Their work cycles were staggered. When one got off the bicycle ergometer the other would got on.

Experimental Phase No. 1 - Results

It was anticipated that the measurements of the physiological responses of a subject to any one of the test conditions, within either environmental condition could be statistically compared to his responses to any of the other test conditions. As it has been mentioned before, the

Table 6. Experimental procedure for one subject, Experimental Phase No. 1 for NH-H-H-NH test condition sequence during an environmental condition.

		MEASUREMENTS					
	Activity	Pulse	Temperatures			Oxygen	Comments
Time	Level	Rate	Rectal	Skin	Oral	Consump.	
4:00 pm	Standing						Weighed nude, S. inserts own rectal probe, rectal probe checked visually. S. dressed in shorts goes to pre-test room.
4:04	Standing						Height is measured (1st day only).
4:05	Sitting	x	x		x		S. is outfitted with skin sensors. T_c monitored at 5 min. intervals to determine BCT.
4:45	Standing						Walks to shower room, removes shorts, weighed outfitted, dresses with shorts and sneakers.
4:55	Standing		x				Check BCT, if at equilibrium
5:00							S. goes into test room, all loads plugged in.
5:01	Sitting	x	x	x			First condition NH begins.
5:05	"	x	x	x			Sits on chair.
5:10	"	x	x	x			" " "
5:15	Sitting	x	x	x			" " "
5:16	Stands						Gets on bicycle ergometer.
5:20	Sitting	x	x	x		x	Starts breathing O_2 at <u>Rest</u>.
5:25	Pedals	x	x	x		x	Starts <u>Work</u> while breathing O_2.
5:30	"	x	x	x		x	Works while breathing O_2.
5:34:30	"	x				x	
5:35	Sitting	x	x	x		x	Stops work while breathing O_2.
5:35:30	"	x				x	Breathing O_2.
5:40	"	x	x	x		x	Recovering from work, breathing O_2.
5:41	"					x	Stops breathing O_2.
5:45	"	x	x	x			Sits on bicycle ergometer
5:46	Stands						Gets off bicycle ergometer
5:50	Sitting	x	x	x			Sits on chair
5:55	"	x	x	x			" " "
6:00	"	x	x	x			Condition NH ends. Puts on headdress.
6:01	"						Condition H begins.
7:00							Above one hour cycle is repeated. First Condition H ends.

Table 6 (concl.)

Time	Activity Level	MEASUREMENTS Pulse Rate	Temperatures Rectal	Skin	Oral	Oxygen Consump.	Comments
7:01							Second Condition H begins.
		x	x	x		x	One hour cycle is repeated.
8:00							Socond Condition H ends, removes Headdress
8:01							Second Condition NH begins
		x	x	x		x	One hour cycle is repeated
9:00							Second Condition NH ends
9:01							Leads are unplugged. S. loaves test room. Goes to shower room and is dried, removes shorts and sneakers.
9:05							Woighed outfitted.
9:08							Wraps sheet around him. Goes out of shower room to pre-test room, plugs in T_c lead.
9:10			x				Removes skin sensors. When BCT + 0.5 is approached, S. goes to showor room, dries, and removes T_c probe. Weighed nude. End of test sequence.

term "test condition" refers to whether or not the subject wore the headdress. Therefore, there are four possible combinations of environmental and test conditions: Cool, no headdress; Cool, with headdress; Hot, no headdress; and Hot, with headdress. The above expectations were based on the previously stated assumptions, that the test conditions in either environment were immediate, independent and comparative. Before describing the evaluation of the physiological indices it is probably worthwhile to describe some of the events that were observed during this experimental phase.

The first exposure to the cool condition lasted $5\frac{1}{2}$ hours instead of the soheduled four. The second exposure lasted $4\frac{1}{2}$ hours. This was due to

several mechanical breakdowns of the experimental equipment and/or to the unfamiliarity of the experimenter with the equipment. Both subjects completed the four scheduled test conditions during each of the exposures to the cool condition without incidents.

It was found that when a subject started the exposure to the hot condition without the headdress, that he could complete a total of three cycles. The first was without the headdress and the other two with the headdress; but when the headdress was removed after the third cycle he would within a few minutes complain of muscular weakness accompanied by a severe headache and would ask to be removed from the test room. If the subject started the exposure to the hot condition with the headdress he could barely complete two cycles; one with the headdress and the other without the headdress, before he would complain of faintness and weakness. When the headdress was removed after wearing it for two consecutive cycles in the hot environment both the subject's core and skin temperature would decrease about 0.2° C. (0.4° F.) while his head temperature would increase as much as 2.8° C. (5° F.) within a few minutes. This was accompanied by flushness of the face. His heartbeat would vary up and down and the nurse reported that it got weaker. This experimenter associated these occurrences to the onset of thermal shock. Guyton (1966) described the general effects of shock on the body. He stated that in shock the metabolic processes of the heart are depressed and therefore, the distribution of oxygen to the tissues is reduced. Because of this the person feels severe muscular weakness. In turn, the lower metabolism reduces the amount of heat generated by the body with a resulting decrease in internal temperature.

Rubenstein, Meub, and Eldridge (1960) report that the rewarming of the surface of the body after immersion in cold water resulted in the

paradoxical further cooling of the core (T_c decreased) as a result of the increased blood flow through the large mass of the cold skin and subcutaneous structures. If an analogy is made, between the head in this case and the body in Rubenstein's, et al (1960) case, a flow of warm blood into the coldor tissues of the head with a consequent docrease in T_c occurred. It appears as if upon removal of the headdress after wearing it in a hot environment either an onset of thermal shock or the phenomena described by Rubenstein, et al (1960) may occur, depending on the length of time the headdress had been worn. Because of these incidents the scheduled experimental design for Experimental Phase No. 1 could not be completed during the exposure to the hot environmental condition. Table 7 shows the test conditions completed during the Experimental Phase No. 1.

Table 7. Test conditions completed during Experimental Phase No. 1.

Environmental Condition	Subject	Test Sequence 1	2	3	4	Date
Cool	BAK	H	NH	NH	H	9/13/66
		NH	H	H	NH	9/16/66
	CHA	NH	H	H	NH	9/13/66
		H	NH	NH	H	9/16/66
Hot	BAK	NH	H	H		9/14/66
		H	NH			9/15/66
	CHA	H	NH			9/14/66
		NH	H	H		9/15/66

Key: H = With Headdress, NH = Without Headdress

The analysis and evaluation of the measurements obtained during Experimental Phase No. 1 follow.

Heart Rate and Oxygen Consumption

Müller (1953) described a technique for obtaining comparative measurements of the physiological cost from the Recovery Pulse Sum (RPS) for various rates and tempos of work at different environmental conditions. The Recovery Pulse Sum is defined as the sum of the pulses above the resting level from the end of the exercise until the end of recovery, or as the area under the pulse curve during the period required to bring the pulse rate down to normal after exercise. He associated the RPS to the maximum energy expenditure above the basal metabolic level, and called this maximum energy expenditure the Endurance Limit (EL). He assigned a value of 4 Kcal/min. to the endurance limit in man. He stated that if the work is done above the EL, the heart rate during work does not attain a constant level, but continues to rise, and the better indicator of physiological cost is the RPS. His reasoning for this is that recovery depends on the supply of blood provided to the fatigued muscles and that an abundant supply may be achieved by a prolonged increase in cardiac output. Once the muscles have been nourished the pulse rate returns to its normal resting rate.

Therefore, it is inferred that the metabolic rate must also be considered when evaluating the heart rate in test situations that involve work. A source of confusion when using the terms metabolic rate and work output is their relationship. The metabolic rate is the measurement of work which is traditionally defined as force times the distance through which the force acts. The work output of a human is related to his metabolic rate

through the rate of energy conversion and the group of the muscles used to accomplish the work. In compliance with other literature (Bobbert, 1960, and others) this rate of energy conversion will be referred to as the energy conversion efficiency of the system. If Muller's (1953) Endurance Limit of 4 Kcal above the basal metabolic rate is to be considered, a conversion factor must also be used. This conversion factor varies, according to Karpovich (1965), from 4.68 to 5.04 Kcal/liter of O_2 depending on the combination of fat, carbohydrate or protein being oxidized. For closed circuit measuremonts of oxygen consumption, such as the ones obtained in this experiment, he recommends the value of 4.68 Kcal/liter of O_2 for a subject on an ordinary mixed diet. Several factors, besides diet, influence the conversion efficiency of man. Some of them are fitness and degree of fatigue of the individual and of the muscles used to do the work, and any variations of the metabolic rates due to environmental conditions or other causes. Bobbert (1960) found that the energy conversion efficiency for pedalling a bicycle ergometer in a comfortable environment was 22.1% of the maximum energy expenditure during work.

The metabolic rates throughout the experiment were calculated, as previously described, from the Volume/Time graphs. Two rates were obtained, one for the resting period before work and the other one representing the net cost of work. According to Miller (1954) the net cost of work must account for the oxygen consumed during work in excess of the resting rate as well as for that consumed during the six minutes of recovery in excess of the resting time. Both of these ratos were plotted using cartesian coordinates. The first plot grouped the metabolic rates versus test cycles per test condition irregardless of days. It consisted of the results of two days (a Tuesday and a Friday) juxtaposed for each test condition. This

first plot was incoherent because of large fluctuations between the values which distorted the picture. The second plot grouped the metabolic rates versus the test cycles per day regardless of test conditions. This plot showed a general trend toward higher oxygen consumption as the experiment progressed regardless of environmental conditions and a trend toward lower oxygen consumption from the first to the last cycle within a day for either sequence of test conditions. The fluctuations per day per subject were not as large as those found when the data was grouped by test conditions. Therefore, it is apparent that an interaction between test conditions and days exists in the metabolic data.

For unity and ease of reading, the evaluation of experimental metabolic and cardiac data for the test conditions will be stated according to the environmental condition in which they were observed. Within each environmental condition a comparison of physiological behavior during each sequence of test conditions will be discussed.

Cool Condition. In handling the experimental heart rate data for Phase No. 1, the observed rates of each subject during an environmental condition, following either sequence of test conditions, were plotted versus time using cartesian coordinates. (See Plate VIII.) The areas under the pulse-time curves above the basic pulse rate (BPR) for each test condition were measured with a planimeter (one sq. inch equals 1000 pulse-minutes). These areas comprised the period between the end of work and the time at which the heartbeat was back at its basic level. The number of pulse-minutes units obtained were considered to be the RPS.

It was attempted to find significant differences between test conditions (Headdress vs. No Headdress), between test days (First or Second Exposure to Environmental Condition) and between subjects (CHA or BAK) by

EXPLANATION OF PLATE VIII

Fig. 10. Graph of Heart Rate vs. Exposure Time showing Recovery Pulse Sum areas and Basal Pulse Rate (BPR) for subject BAK during first exposure to the Cool Condition in Experimental Phase No. 1.

PLATE VIII

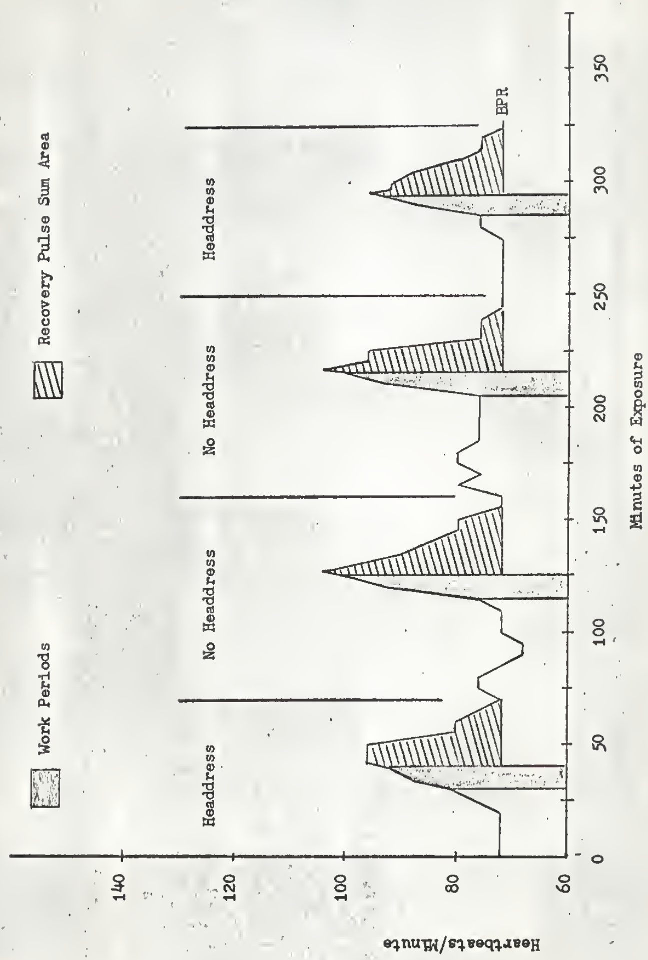

Fig. 10

using the RPS values observed during the cool condition in a three-way Analysis of Variance. The main effects considered were Headdress, Days and Subjects. No significant differences were found between the main effects, but a significant interaction between Days x Subjects was found (see Table 8). This interaction can be explained by the fact that adjustment of the subjects to the work situation had occurred during the intervening two days between exposures to the Cool Condition during which the subjects had worked in the Hot Condition.

Table 8. Three-way Analysis of Variance using Recovery Pulse Sum values.

Source	D/F	M.S	F
Headdress	1	1.5625	.31
Days	1	45.5625	.04
Subjects	1	22.5625	---
Headdress x Days	1	189.0625	3.16
Headdress x Subjects	1	5.0625	.08
Days x Subjects	1	1040.0625	17.39**
Headdress x Days x Subjects	1	33.0625	.55
Residual	8	59.8125	
Total	15		

$F_{(1,8).05} = 5.32$

The Wilcoxon Matched-pair Signed-ranks non-parametric statistical test was used in an attempt to find significant differences in oxygen consumption rates between test conditions. The values used for comparison were the rest O_2, the net work O_2 and the sum of both of these values. It

was assumed by this experimenter that the sum of the rest O_2 plus the net work O_2 could be considered to represent the maximum energy expenditure for the work situation. No significant differences were found by using these criteria. It was mentioned previously that a large variation in the values of the rest O_2 (maximum range from 192.1 to 366.2 cc/min., minimum range from 232.1 to 297.0 cc/min.) had been observed for the subjects within the four work cycles of a test condition. These values refer to the grouping of metabolic rates by test conditions regardless of days. The magnitude of the interaction between subjects and days and of test conditions and days was evident when these ranges were compared to the ranges obtained within the days regardless of test conditions.

It was observed that for most situations the net work O_2 was inversely proportional to the rest O_2, thus when the resting O_2 consumption was low the net O_2 was high and vice versa. Muller (1953) had stated that the RPS was related to the maximum energy expenditure; therefore, the RPS was plotted versus the rest O_2, the net work O_2, and the maximum energy expenditure (sum of rest O_2 plus net work O_2). The Spearman Rank Correlation Method was used to quantify the similarity between these two factors. No significant conrrelation were found between the RPS and the rest O_2 or between the RPS and the net work O_2 for either test condition, nor for the maximum energy expenditure when the subject worked without the headdress (see Fig. 11), but a significant negative correlation ($r_S = -.76$) was found when the subject worked with the headdress (see Fig. 12). The reason for the different levels of correlation between the RPS and the maximum energy expenditure may be that the six minute period during which the subjects breathed oxygen after stopping work was not sufficient, thus what is called

EXPLANATION OF PLATE IX

Fig. 11. Graph of Maximum Energy Expenditure vs. Recovery Pulse Sum for both subjects when working in the Cool Condition without the headdress during Experimental Phase No. 1. No significant correlation ($r_S = -.03$).

Fig. 12. Graph of Maximum Energy Expenditure vs. Recovery Pulse Sum for both subjects when working in the Cool Condition with the headdress during Experimental Phase No. 1. Significant (= .05) negative correlation ($r_S = -.76$).

PLATE IX

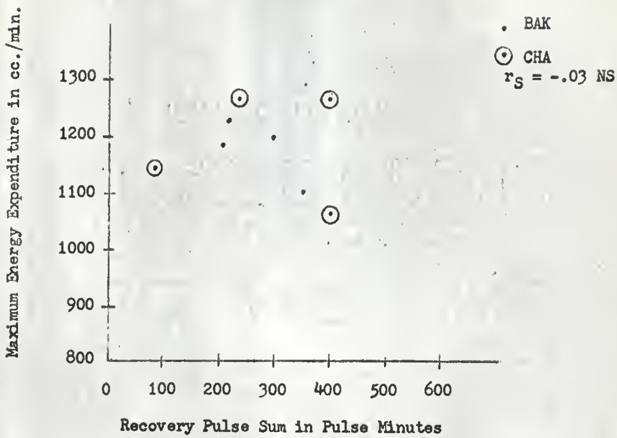

Fig. 11

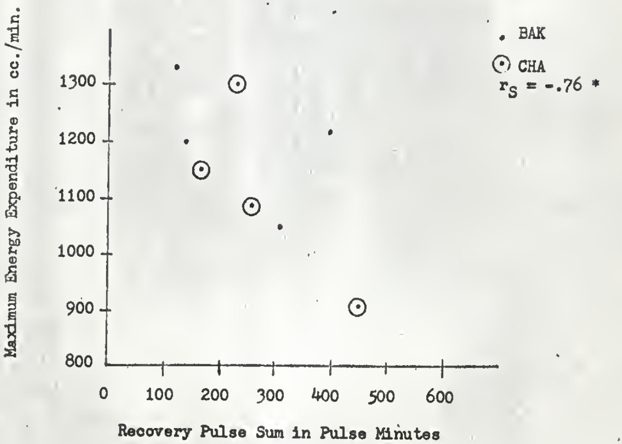

Fig. 12

here "net cost of work" is not an accurate representation when the subject worked without the headdress.

The efficiency of energy conversion was calculated by using 4.86 Kcal/liter of O_2 @ STP/min. for the conversion factor. The net oxygen consumption for both subjects during work was averaged and converted to energy expended. The work output of 0.1 HP @ 40 rpm was calculated to be equivalent to 1.069 Kcal/min. The ratio between work output and energy expended while wearing the headdress was found to be 25.2 percent. The ratio when working without the headdress was 24.0 percent. Both values are slightly higher than Bobbert's (1960) results for pedalling a bicycle ergometer in comfortable conditions, which may also indicate insufficient recording time for full recovery payment of the oxygen debt.

Under the section describing the measurements it was mentioned that the heart rate was measured 30 seconds before stopping work and 30 seconds after stopping work. The purpose of this was to check on a phenomena previously observed by this experimenter in a pilot project and described by Morris (1964). It had been observed that upon stopping work the heart rate increased instead of following the usual exponential decline. The occurrences of an increase in heart rate upon stopping work were counted for both test conditions in the comfortable environment. It was found that during the first day of exposure this phenomena occurred for both subjects in both test conditions. During the second exposure, three days after the first exposure and having been exposed to the hot condition during the intervening two days, the phenomena did not occur in any of the test conditions for either subject. It appears that in the comfortable environment this phenomena is dependent upon the physical fitness or the degree of

adaptation to the work rate of the individuals involved.

Hot Condition. A very meager amount of data was obtained for the hot condition during this experimental phase. Instead of the expected sixteen cycles only ten were completed, six with the headdress and four without the headdress (see Table 7). As it has been described before, an onset of thermal shock occurred when removing the headdress after wearing it two consecutive cycles in the hot environment. Because of this, and other factors which will be described in detail later, statistical evaluation of the data was untenable.

Figure 13 graphically describes the incomplete recovery observed during the test conditions. Before the heart rate returned to normal, a new test condition had been initiated and an overlap between test conditions occurred. Because of this and the fact that the heart rate did not return to the basic pulse rate (BPR) after work in most of the test conditions, the RPS was not calculated. It was also observed by projecting the recovery pulse curve that it would take longer to return to the BPR (nearly 50 minutes) and that the oxygen oonsumption during recovery was still measured during the six minutes.

The ranges of oxygen consumption during rest were greater (maximum range from 175.8 to 395.9 cc/min., minimum range from 361.0 to 401.6 cc/min.) than for the cool condition. These values refer to the grouping of metabolic rates by test conditions irregardless of days. The net oxygen cost of work was assumed to be not representative of the energy expenditure during work. To check on this factor the energy conversion efficiency was calculated for each test condition in the same manner as before. The results showed a large disparity for the efficiency of work with the headdress in relation to the efficiency of work without the headdress. The calculated

EXPLANATION OF PLATE X

Fig. 13. Graph of Heart Rate vs. Exposure Time showing the Incomplete Recovery Pulse area observed during a test condition and the overlap of the projected recovery area into the next condition for subject CHA during second exposure to the Hot Condition in Experimental Phase No. 1.

PLATE X

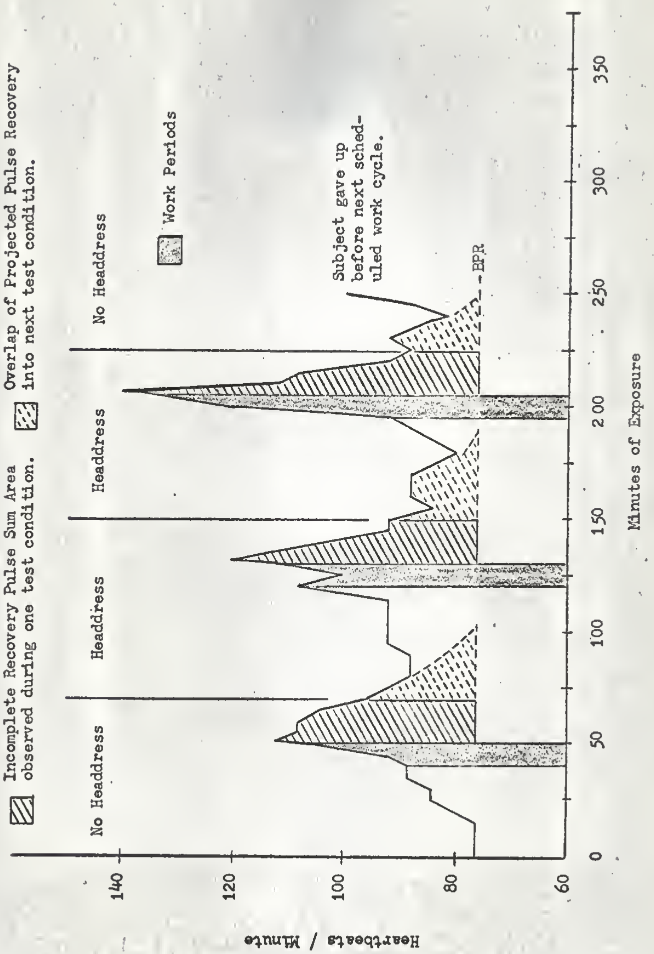

Fig. 13

energy conversion efficiency for the former was 32.2% and for the latter 25.9%. A high energy conversion efficiency indicates lower oxygen consumption for the same rate of work. It was expected that the efficiency of work without the headdress in the hot condition would increase because of lower oxygen consumption in hot environments reported by Wyndham, et al (1962) that were previously mentioned in the introduction of this paper. The efficiency for work with the headdress in the hot condition was expected to remain approximately the same as for the cool condition without the headdress. This reversal between the expected and the observed results again points out that the metabolic data was unrepresentative.

The occurrences of an increase in heart rate upon stopping work were counted for both test conditions in the hot-humid environment. It was found that this phenomena occurred after all the work cycles in this environment regardless of test conditions. Therefore, this phenomena was observed during the first three days of Experimental Phase No. 1 regardless of test or environmental conditions, and its occurrence so far points toward the adjustment of the subjects to the work rate since it was absent in the last day of this experimental phase.

Core, Skin and Head Temperatures

The core temperatures (T_c) obtained every five minutes during the test conditions, were averaged to obtain the mean core temperature ($T_{\bar{c}}$) for each test condition. The four skin temperatures measurod at the arms and legs were averaged arithmetically to obtain what is considered here as a represontative skin temperature (T_s) for every five minutes of the test exposure. The representative skin temperatures (T_s) for each test condition were averaged to obtain the mean skin temperature ($T_{\bar{s}}$) for each test

condition. The five skin temperatures measured at the head were averaged arithmetically to obtain what is considered here to be a representative head temperature (T_h) for every five minutes of the exposure. The representative head temperatures (T_h) were averaged to obtain the mean head temperature ($T_{\bar{h}}$) for each test condition. The mean temperatures of the skin and head may not be representative of the modal temperature because there was a considerable time lag for the temperatures to reach equilibrium after entering a new test condition. For ease of reading and for unity of the text, both environmental conditions will be dealt with separately.

<u>Cool Condition</u>. The mean rectal temperatures ($T_{\bar{c}}$) of each test condition were compared using the Wilcoxon Matched-pair Signed-ranks test by matching the sequence of work periods of each subject to evaluate any differences between test conditions. To reduce individual variability each $T_{\bar{c}}$ was reduced by subtracting the subject's initial core temperature (T_{c_i}) observed at the start of each test condition. No significant differences were found between test conditions, but there were significant effects of days and of subjects. Both subjects reacted differently to the headdress and their adaptation to the test conditions in different days made statistical evaluation of differences between test conditions impossible. The effect of increasing internal temperature with repeated work cycles also influenced the results, specifically when the headdress was worn during the first and last cycles (H-NH-NH-H sequence) of the exposure rather than during the middle two cycles (NH-H-H-NH sequence). With the H-NH-NH-H sequence the general trend of the $T_{\bar{c}}$ was up, but with the NH-H-H-NH sequence the general trend was down. (See Fig. 14 and Fig. 15.)

The range of T_s within any test condition was larger than for the

EXPLANATION OF PLATE XI

Fig. 14. Core, Skin and Head Temperatures (T_c, T_s and T_h respectively), observed on subject BAK during the Cool Condition in Experimental Phase No. 1 for the NH-H-H-NH sequence, versus Exposure Time.

PLATE XI

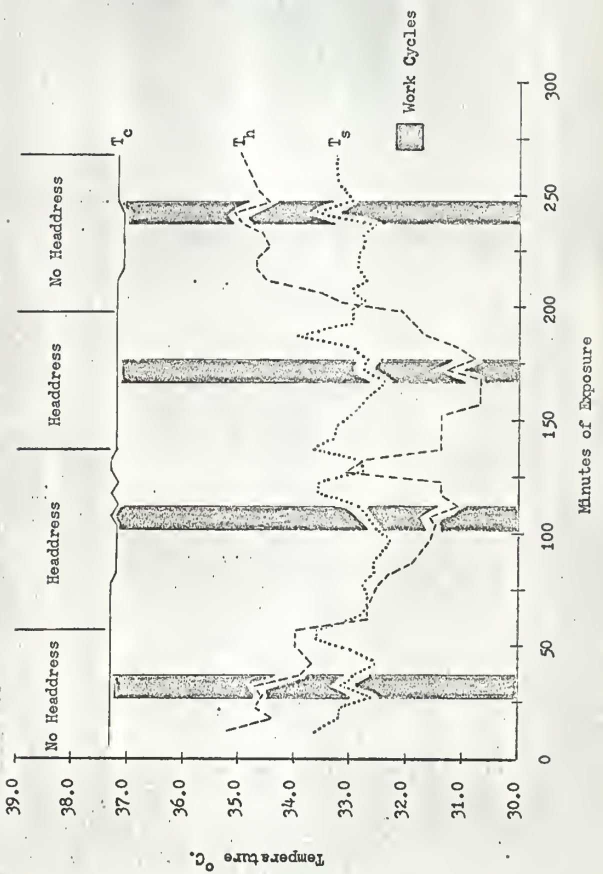

Fig. 14

EXPLANATION OF PLATE XII

Fig. 15. Core, Skin and Head Temperatures (T_c, T_s and T_h respectively), observed on subject CHA during the Cool Condition in Experimental Phase No. 1 for the H NH NH H sequence, plotted versus Exposure Time.

PLATE XII

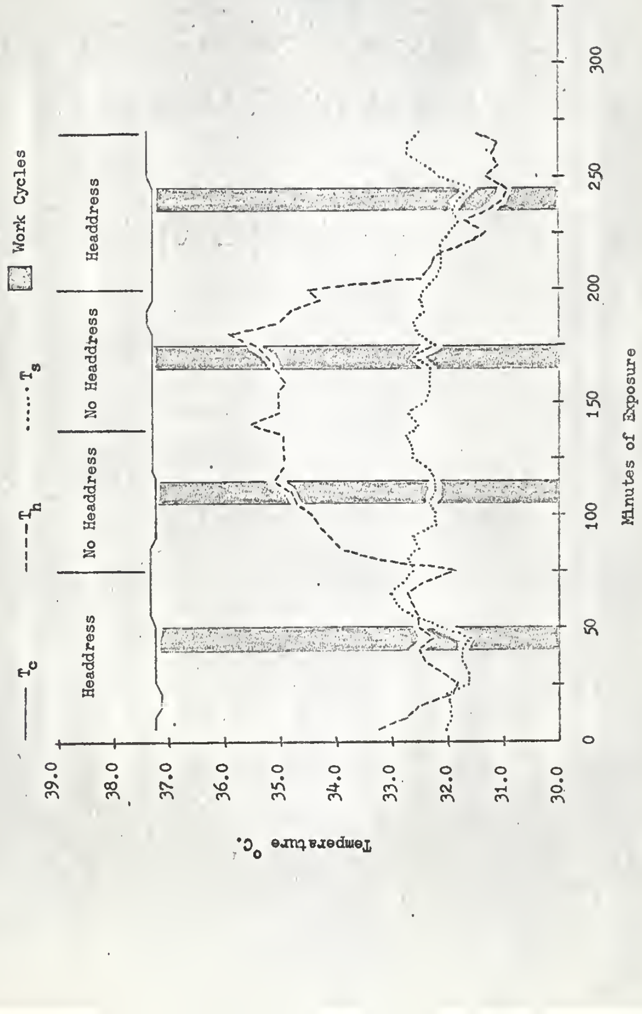

Fig. 15

rectal temperatures. It appeared that the fluctuations of these values were subjected to the initial skin temperature (T_{s_i}) for the test condition and to the sequence of test conditions. It was observed that when T_s decreased throughout the exposure, T_c tended to increase and vice versa. This indicates thermal balance throughout the exposure in spite of the test condition and may in part be responsible for the variability observed in the resting metabolic rates. There were no significant differences in mean skin temperatures ($T_{\bar{s}}$) found between test conditions. The magnitude of the difference between the average of the mean skin temperatures ($T_{\bar{\bar{s}}}$) of both test conditions indicates that the subgroups used in the evaluation were not rationally composed. It also points out to unequal carryover effects between test conditions. It appears that for this environmental condition the installation of the headdress affects the body thermoregulatory mechanisms at a slow rate, but to a larger degree, than the removal of the headdress does. Upon removal of the headdress the return to "normal" thermoregulatory behavior is faster.

Wyndham (1965) reported a study conducted to establish meaningful relationships between sweat regulation and the levels of T_s and T_c. He concludes that the onset and the rate of sweating is interdependent upon the magnitude and characteristic of the effect of change in the T_c and the level of T_s and vice versa. There is a range in which T_s is relatively insensitive as a thermoregulator of heat (i.e. T_s about 26° C.). At this insensitive range the effect on the onset of sweating of 1° C. change in T_c is 10 or 12 times greater than the same change in T_s. In the neutral range (i.e. T_s about 33° C.) the effect on the onset of sweating of 1° C. change in T_c is 5 or 6 times greater than the same change in T_s. In the sensitive range (i.e. T_s about 36° C.) the effect on the onset of sweating

of 1° C. change in T_c is 4 or 5 times greater than the change in T_s. In order to check these relationships and the effect of the headdress on them the following events were considered. During and after the work periods the skin temperature (T_s) climbed up and as sudomotor activity ensued it would start its downward decrease. (See Fig. 15.) The climb of T_s would be more pronounced when the subject wore the headdress. To investigate the above mentioned relationships and a possible shifting in the sudomotor activity threshold, the highest skin temperature (T_s) observed during a test condition, which was assumed to indicate the onset of sudomotor activity, was plotted versus the core temperature (T_c) that was observed concurrently with it (see Fig. 16). Wyndham's (1965) relationships for the neutral range did not hold since the relationship was about 3 to 1, but this may be attributed to the levels of T_c, to measurement errors and of the errors in the assumption on which this comparison was made. It was also found that the headdress appeared to inhibit sudomotor activity in CHA while prompting it in BAK. The results seem to indicate that when the subjects wore the headdress the sudomotor activity threshold would shift toward a position interpreted as of decreased variability between subjects or of having T_c be more representative of the "internal" temperature that triggers the sensor-effector organs of thermoregulation. It should be explained that the envelope in Fig. 16 contained between the lines representing the threshold of sudomotor activity of both subjects for the test conditions without the headdress is considered by this experimenter to indicate the variability between subjects. The two lines representing the threshold of sudomotor activity for the test condition with the headdress are thus contained within the envelope and interpreted as indicating a decrease in variability possibly due to "internal" blood temperature being closer to

EXPLANATION OF PLATE XIII

Fig. 16. Graph constructed by plotting sets of points which are assumed to represent the onset of sudomotor activity for both subjects during the exposure to the cool environment in Experimental Phase No. 1. The highest skin temperatures (T_s) observed after the work cycles, for both test conditions, were plotted versus the concurrent core temperature (T_c).

PLATE XIII

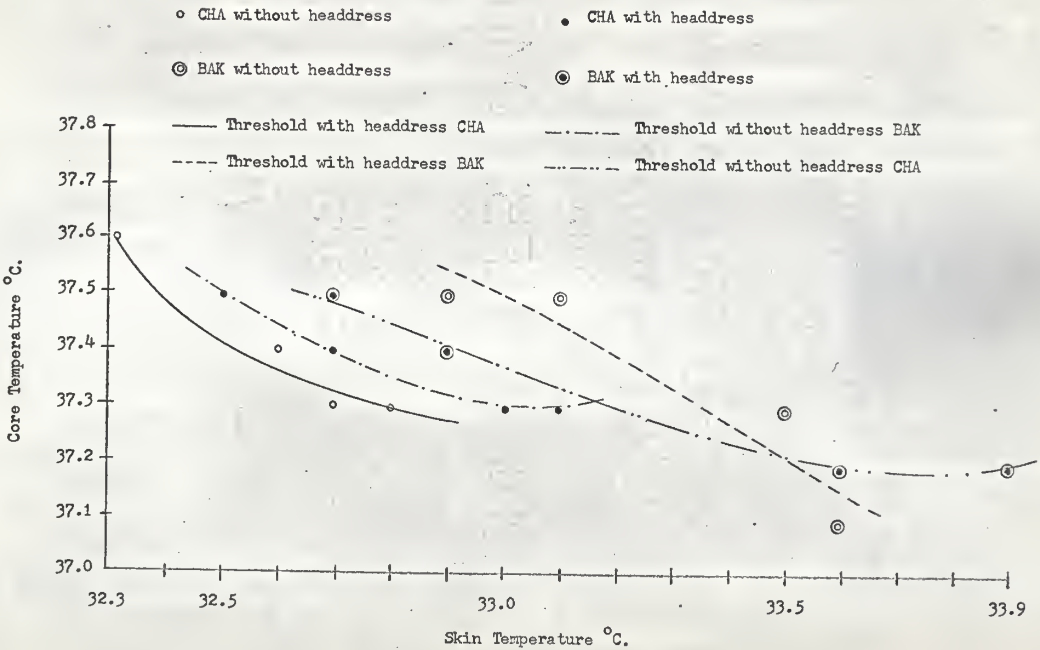

Fig. 16

the measured core temperature.

Head temperatures (T_h) with the headdress were found to be significantly lower than without the headdress, even though the large variability recorded between the time of installation of the headdress and the time that the T_h reached a plateau affected the magnitude of the values thus making the $\bar{T}_h$ for each test condition lower than the modal T_h. The peaks that appear in the T_h curve (Fig. 14 and Fig. 15) suggest that the T_h recorded while the subject was not wearing the headdress reflected a rise in "internal" temperature faster than either the skin or core temperatures. There was no relationship found between the assumed onset of sudomotor activity and the head temperatures.

Hot Condition. No statistical evaluations of the differences between skin, head and core temperatures (T_s, T_h and T_c respectively), for the two test conditions, were made for this environmental condition. The main reason behind this was not only the meager amount of data obtained, but also the differences observed in the behavior of the subjects and the effects added to these differences by other factors. A discussion of the thermoregulatory behavior of each subject will attempt to focus on the differences between test conditions, even if the differences in the subject's response to the test conditions may predominate. All physiological responses appear to be magnified by heat, probably because of the additional thermoregulatory load imposed on the system. It is necessary to mention that thermoregulation takes different forms at different states with different people. There are those whose sweating ability allows them to maintain a greater temperature gradient between T_s and T_c in most types of hot environments. Others additionally or solely reduce their body heat production more readily by decreasing their oxygen consumption. These are

extremes, but many more dynamic alterations or adaptations are occurring simultaneously within the system and the temperature data obtained shows merely the levels of the changes, but not the factors behind the changes.

Three major factors appeared to influence the thermoregulatory behavior of both subjects. The first factor was the initial temperature level (T_{c_i} and T_{s_i}) of each test condition and the initial temperature gradient between T_c and T_s ($T_{c_i} - T_{s_i}$) at the start of a test condition. If body heat storage had already occurred, T_c was high and the gradient between T_c and T_s was small. Leithead and Lind (1964) stated that to maintain thermal equilibrium the skin temperature must be lower than the core temperature by at least 1.0° C. (1.8° F.) so that the body can be capable of transferring adequate quantities of heat from the core to the skin for dissipation to the environment. If the above situation ($T_c - T_s < 1°$ C.) was present when the headdress was installed, it assisted in dissipating heat from the body. But, if it was present when the headdress was removed, either the previously described onset of thermal shock occurred or the prospective endurance of the subject was reduced because of thermal stress.

The second factor includes two variables both of which directly influence factor one. The first variable relates to the inherent thermoregulatory ability of the individual either in the form of heavy sweating or by reducing metabolic heat production as his first line of defense against thermal stress. The second variable relates his inherent physiological response to thermal stress (first variable) to his response to the hot-humid environment with or without the headdress. It is surmised by this experimenter from personal observation and weight loss records that BAK was the heavier sweater of the two and from the oxygen consumption data

that both were able to vary their heat production readily, but that CHA could do so easily. From the results obtained during the cool condition subject CHA's onset of sudomotor activity was inhibited by the headdress toward a higher skin-core temperature combination, while subject BAK's sudomotor activity was prompted by the headdress at a lower skin-core temperature combination. (See Fig. 16.) If these results hold true for this environmental condition they explain why subject BAK was able to maintain a larger gradient between T_s and T_c, while wearing the headdress, than CHA could since in a hot-humid environment T_s increases either because of insufficient evaporative cooling or due to large convective and storage heat gains of the body. One indication of sufficient evaporative cooling for subject BAK while wearing the headdress is shown in Fig. 18 by the greater amount of peaks in the T_s curve when compared to the same curve in Fig. 20 for subject CHA under the same test condition. If it is assumed that each of those peaks (see Fig. 18) represent the onset of sudomotor activity, then their absence (see Fig. 20) may indicate greater dependency on the conductive cooling because of inhibition of sudomotor activity by the headdress. This points out a large interaction for the subjects' responses between test and environmental conditions.

The third factor relates the first two factors and concerns the sequence of test conditions and the effect that the test sequences had on the subjects' thermoregulatory behavior. First the behavior of both subjects without the headdress regardless of sequence will be explored. Subject CHA's T_s and T_h rose <u>above</u> the concurrent T_c during and after work without the headdress. Under the same conditions subject BAK's T_s and T_h rose to below the concurrent T_c. This difference in their behavior may be attributed to BAK's heavier sweating. Although the environmental humidity

EXPLANATION OF PLATE XIV

Fig. 17. Core, Skin and Head Temperatures (T_c, T_s and T_h respectively), observed on subject BAK during Hot Condition in Experimental Phase No. 1 for the H-NH-NH-H sequence, plotted versus Exposure Time.

Fig. 18. Core, Skin and Head Temperatures (T_c, T_s and T_h respectively), observed on subject BAK during the Hot Condition in Experimental Phase No. 1 for the NH-H-H-NH sequence, plotted versus Exposure Time.

PLATE XIV

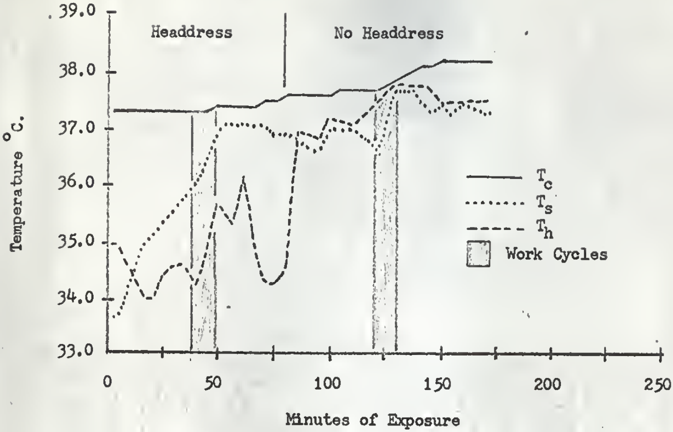

Fig. 17

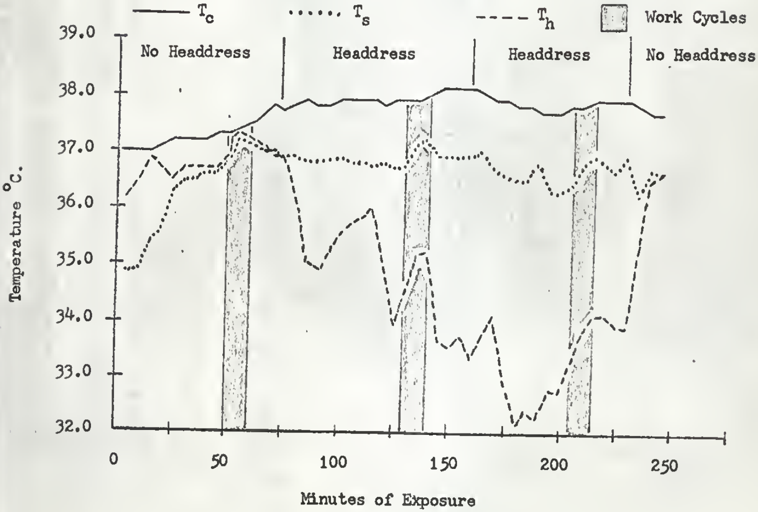

Fig. 18

EXPLANATION OF PLATE XV

Fig. 19. Core, Skin and Head Temperatures (T_c, T_s and T_h respectively), observed on Subject CHA during the Hot Condition in Experimental Phase No. 1 for the H-NH-NH-H sequence, plotted versus Exposure Time.

Fig. 20. Core, Skin and Head Temperatures (T_c, T_s and T_h respectively), observed on subject CHA during the Hot Condition in Experimental Phase No. 1 for the NH-H-H-NH sequence, plotted versus Exposure Time.

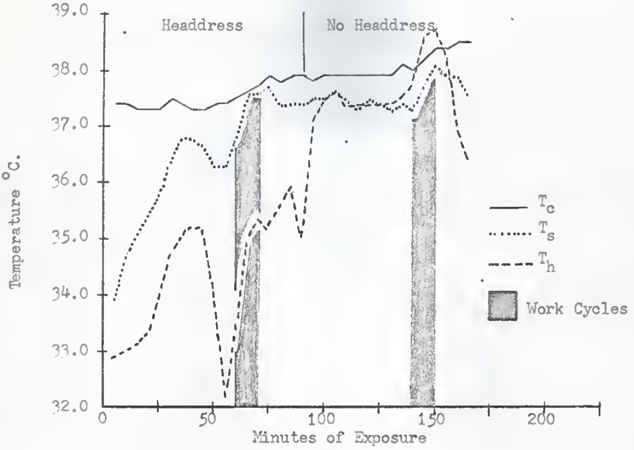
Headdress
No Headdress
39.0
38.0
37.0
36.0
35.0
34.0
33.0
32.0
Temperature °C.
T_c
T_s
T_h
Work Cycles
0
50
100
150
200
Minutes of Exposure

Fig. 19

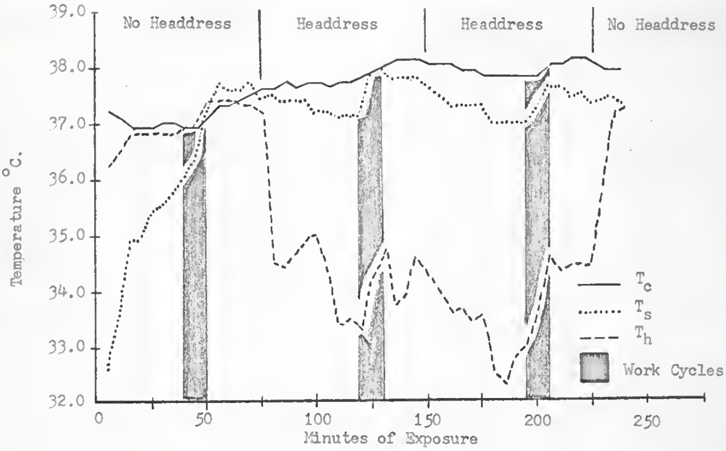
No Headdress
Headdress
Headdress
No Headdress
39.0
38.0
37.0
36.0
35.0
34.0
33.0
32.0
Temperature °C.
T_c
T_s
T_h
Work Cycles
0
50
100
150
200
250
Minutes of Exposure

Fig. 20

inhibited evaporative cooling and most of their sweat dropped to the floor. BAK was able to obtain a larger amount of heat dissipation through this channel than CHA did. Leithead and Lind (1964) state that if skin temperature exceeds core temperature, the body is not only unable to lose heat, but it is continually gaining heat and the individual's limit of endurance is decreased. Heat storage occurred in varying degrees during the first two cycles of the exposure to the environment regardless of the sequence of test conditions due to convection and heat storage gains which were not offset by either radiation, evaporative or conductive losses. When the sequence NH-H-H-NH was in effect, T_c decreased during the third cycle due mainly to conductive losses through the headdress. Wyndham (1965) states that the effect on the sweat rate of 1° C. (1.8° F.) rise in T_c is much greater than that of the same rise in T_s. Thus, the interdependency of T_c and T_s on one another appears to shift as the sudomotor triggering mechanisms sense preponderance of one factor over the other. This dynamicity in the system is what makes evaluation of the factors behind the observed changes difficult.

The effect of sequence is confounded by the interaction between environmental and test conditions, the subject's dynamic variability and the unequal carryover between test conditions. When the exposure started without the headdress (sequence NH-H-H-NH shown in Figs. 18 and 20) the subjects' behavior was similar if the inherent thermoregulatory processes of the subjects and their interaction with the test condition are taken into consideration. During the first cycle BAK maintained a larger gradient between T_c and T_s due to his heavier sweating. Therefore, when the headdress was installed at the beginning of the second cycle, CHA had higher storage gains. The headdress inhibited CHA sweating while it

prompted BAK's. Therefore, during the second cycle BAK had a combination of evaporative and conductive cooling capacity in excess of CHA's, and was able to maintain a larger gradient between T_c and T_s. During the resting interval between the second and third cycles, the body heat loss through the headdress was larger than the heat gains from the environment and T_c of both subjects decreased, although the gradient between T_c and T_s remained greater for BAK because of additional cooling due to evaporative capacity while wearing the headdress. During the third work cycle the gain in T_c, although small for both subjects, was greater for CHA since his dissipation of heat depended primarily on conductive rather than on a combination of conductive and evaporative cooling. When the headdress was removed in the hot environment the onset of thermal shock was faster on BAK than CHA. It appeared as if conductive cooling at the head had a greater effect on BAK's thermoregulation mechanism than on CHA's. The onset of thermal shock is attributed to the failure of the sensor-effector organs of the thermoregulatory mechanism to sense preponderance between T_c and T_s. It has been mentioned above that on removal of the headdress in the hot environment, both T_c and T_s decreased while T_h increased rapidly.

When the exposure started with the headdress (sequence H-NH-NH-H shown in Figs. 17 and 19) the inherent thermoregulatory processes of the subjects and their interaction with the test conditions, once more came into play. During the first test cycle the headdress inhibited CHA's sudomotor activity and caused him to store twice as much heat as BAK did ($\Delta T_{c_{BAK}} = +0.3^\circ$ C, $\Delta T_{c_{CHA}} = +0.6^\circ$ C.). At the end of the first work cycle CHA's T_s was equal to his T_c, while BAK was able to maintain a narrow gradient between T_s and T_c. Upon the removal of the headdress and during the interval between the first and second cycles both subjects were able

to maintain similar gradients between T_c and T_s probably due to a combination of restriction in heat production and adequate evaporative cooling. as shown by the storage gains during this period ($\Delta T_{c_{BAK}} = +0.1^\circ$ C., $\Delta T_{c_{CHA}} = +0.1^\circ$ C.). During the second work cycles gains in heat storage ($\Delta T_{c_{BAK}} = +0.2^\circ$ C., $\Delta T_{c_{CHA}} = +0.4^\circ$ C.) were too large to be adequately dissipated by the reduced gradient present between T_s and T_c and consequently a condition of intolerable heat stress occurred that made the subjects request that they be removed from the environment even though their total ΔT_c for the entire exposure was less than the 2° F., which was considered to represent the onset of heat stress. One factor that was brought out by the comparison of the subjects' behavior during the two sequences of test conditions is that of unequal carryover effects between test conditions. It seems that tho effect caused by the removal of the headdress has a variable rate of decay depending on how long the person has worn it. If the headdress was removod after one test cycle (sequence H-NH-NH-H) the effect is not as disturbing to the thermoregulatory mechanisms as if the headdress was removed after two cycles (sequence NH-H-H-NH).

To summarize, several effects appear to interact and to preclude meaningful statistical evaluations of differences between test conditions. Some of thses major interactions are 1) the inherent thermoregulatory ability of tho subjects and its interaction with the test conditions, and 2) the interaction between subjects and days. Both of these major interactions are mainly due to short term and long term adjustment processes of the subjects. Some of the difficulties arise also from the small sample size (2) and from the differences between the two subjects' somatypes as well as differences in physical fitness.

Weight Loss. The subjects were weighed previous to and at the end of the exposure. Because four test conditions were juxtaposed during an

exposure, the weight losses could not be attributed to any of them in particular. They only served as indicators of the magnitude of weight lost by a subject dependent on the sequence followed through the exposure.

Subjective Sensations. Both subjects differed in their sensation of the test conditions. Table 9 shows their voiced opinion of the test conditions.

Table 9. Subjective sensation of test conditions voiced by subjects.

Condition	Cycle No.	Subject BAK	Subject CHA
Cool, With Headdress	1	Very Comfortable	Comfortably Cool
	2	Very Comfortable	" "
	3	Too Cold	" "
	4	Comfortably Cool	" "
Cool, Without Headdress	1	Comfortably Cool	Very Comfortable
	2	" "	" "
	3	Very Comfortable	" "
	4	Comfortably Cool	" "
Hot, With Headdress	1	Very Comfortable	Comfortably Warm
	2	" "	" "
	3	" "	Very Comfortable
	4	-------	-------
Hot, Without Headdress	1	Too Warm	Too Warm
	2	" "	" "
	3	-------	-------
	4	-------	-------

Their subjective sensations reflect their behavior during the test conditions very well. CHA liked it better at a lower temperature than BAK did. The headdress seemed to affect BAK to a higher degree than it influenced CHA.

Experimental Phase No. 1 - Discussion

The primary objectives of the investigation as stated in the problem were 1) to find out if the exposure time of a person in a hot-humid environment would be extended by wearing the headdress, 2) to observe if the blood was actually cooled by the headdress and 3) to determine if any undue side effects resulted from the manipulation of the subject's thermoregulatory mechanisms. The evaluation of these objectives was to be made from statistical determination of differences between test conditions based on the assumptions that the effect of the headdress on the wearer was immediate and that each instantaneous observation obtained from the subjects was independent and comparative. The observations were to be obtained by measuring six dependent variables every five minutes and by measuring a seventh continuously for 21 minutes during every hour of exposure to four test conditions, which were presented in two sequences used to counterbalance the effects of the exposures to both test and environmental conditions. During the first four days several factors indicated that the interactions between organic, reciprocative and physical variables ever present in environmental research were making statistical evaluation of differences between test conditions untenable.

The experimental design specifically constructed to counterbalance the effect of several of these variables was confounding the data. It has been pointed out in the Results that the sequences of exposure to the

environmental and to the test conditions were contributing long and short term adaptations which appear to oppose each other. The effects of these interactions were considered to overshadow the effects of the headdress.

It became apparent, at the end of the first week of experimentation, that the objectives of the investigation had been only partially accomplished. Because of the incidents that terminated the exposures to the hot condition, the potential of the headdress for extending exposures in hot-humid environments was still in doubt. The blood cooling capability of the headdress was indicated by the lowering of T_c when following the sequence NH-H-H-NH during the exposure to the hot condition. Thermal balance maintained during the exposures to the cool condition when following either sequence provided evidence that thermoregulation was not disturbed, but rather that the triggering mechanisms shifted their thresholds of operative range. The onset of thermal shock upon removal of the headdress in the hot environment disclosed the undesirability of this procedure. It was believed that this occurrence resulted indirectly as a side effect of the headdress and as a result of poor experimental design.

The relationships obtained between the RPS and the observed metabolic rates were found wanting. The six minute recovery period "scheduled" for the determination of recovery oxygen consumption yielded incomplete and unreliable information. The recovery time allowed, during the exposures to the hot environment, for one test condition prior to starting another test oondition was insufficient and created an overlap between test conditions which precluded the calculation of the RPS. Furthermore, breathing of pure oxygen during the work cycles may have been responsible for O_2 saturation in the blood stream which may have inhibited certain sensory mechanisms and consequently indiscriminately altered the physiological

behavior of the subjects from one test condition to another.

Unequal carryovers between test conditions, in reference to both magnitude and rate of decay of effects associated or attributed to them, made the means of the subgroups used for evaluation of significant difference non-representative. In this case magnitude refers to the amount of change and rate of decay to the time duration of the effect. Unequal carryover effects were evident in the measurements of practically all of the physiological indices.

The measurements of the physiological indices, although acceptable within the limitations stated in their description, may not have been the proper indicators of the behavior being studied. On several occasions, a reference was made to the "internal" temperature being somewhat disassociated to the T_c observed. It is considered by this experimenter that the splachnic vasoconstriction that occurs to maintain peripheral resistance during subcutaneous vasodilatation may disassociate T_c from the "internal" temperatures that trigger the sensor effector organs of sudomotor activity.

To paraphrase Cherry (1957): The human being is an intergrated organism whose sensor-effector organs are not independent, but mutually dependent. His responses are made depending on the conditions at all the sense organs, on the association to prior stimuli and to the meaningfulness of the stimuli. A human being is dependable and adaptive, each response may change after every experience. His functional parameters are not fixed, as they may depend on the stimulus itself, its environment and even on his motivation at the moment of the stimuli. The entire field of human physiology is subjected to individual differences and adaptation of individual responses to stimuli. To attempt acceptable statistical evaluation based on fixed and comparative parameters while varying the stimuli over

wide ranges within short spans of time undoubtedly makes these responses non-independent with regard to any one stimulus.

Experimental Phase No. 2 - Method

It was obvious after the first four days of experimentation that if the objectives of the investigation were to be fulfilled, the experimental design had to be changed. A better understanding had been gained from the thermoregulatory processes altered by the headdress and it was evident that the basic assumptions stated for the experiment were in error. Therefore, to take full advantage of the headdress' potential, the experimental design was changed for the remaining four days and will be referred to as Experimental Phase No. 2.

Description of Experimental Design and Procedures.

The objective was to have each subject experience four work cycles twice (one with and one without the headdress) to both the Cool and the Hot Environmental Conditions so that comparisons between test and environmental conditions could be made. To satisfy this requisite the subject was to be exposed to the four environmental conditions (two Cool and two Hot) described previously without varying the test condition (H or NH) during the exposure period. Activity rate was the same as in Experimental Phase No. 1; he was to pedal the bicycle ergometer at a rate of 0.1 hp @ 40 rpm for ten minutes during each hour of exposure. In this manner each environmental condition would contain four similar, although sequential, test conditions. The experimental design for Experimental Phase No. 2 is shown in Table 10.

Evaluation of the metabolio data had not been made at this time and the experimenter was not aware of the incomplete measurement of recovery

Table 10. Experimental design of Experimental Phase No. 2.

Day	Environmental Condition	Test Condition Sequence - Subjects BAK	CHA
Monday	Cool	Headdress (H-H-H-H)	No Headdress (NH-NH-NH-NH)
Tuesday	Hot	No Headdress (NH-NH-NH-NH)	Headdress (H-H-H-H)
Wednesday	Hot	Headdress (H-H-H-H)	No Headdress (NH-NH-NH-NH)
Thursday	Cool	No Headdress (NH-NH-NH-NH)	Headdress (H-H-H-H)

Key: H = With Headdress, NH = Without Headdress

oxygen consumption. Therefore, the experimental procedure was exactly the same as in Experimental Phase No. 1 with the exception that only one of the two subjects tested in an environmental condition wore the headdress throughout the four hour exposure period. Location and frequency of measurements, activity cycles, duration and severity of environmental conditions remained the same as they were for Experimental Phase No. 1. To prevent the possible onset of thermal shock at the end of the hot exposures, the headdress was removed in the test room, but the subject immediately went to the pre-test room where the temperature was approximately 26.7° C. (80° F.) and 40% humidity with an air velocity of about 76.5 cm/sec. (150 fpm).

Before describing the evaluation of the physiological indices it may be worthwhile to mention that the experimental design for Experimental Phase No. 2 was not completed. After three work cycles without the headdress in the hot environment, the core temperature of both subjects rose 1.1° C. (2° F.) above the basic core temperature (BCT) and in compliance

with regulations the subjects terminated their exposure. Table 11 shows the test conditions completed during Experimental Phase No. 2.

Table 11. Test conditions completed during Experimental Phase No. 2.

Environmental Condition	Subject	Test Sequence 1	2	3	4	Date
Cool	BAK	H	H	H	H	9/19/66
		NH	NH	NH	NH	9/22/66
	CHA	NH	NH	NH	NH	9/19/66
		H	H	H	H	9/22/66
Hot	BAK	NH	NH	NH		9/20/66
		H	H	H	H	9/21/66
	CHA	H	H	H	H	9/20/66
		NH	NH	NH		9/21/66

Key: H = With Headdress, NH = Without Headdress

Experimental Phase No. 2 - Results

It has been stated in the Discussion of Experimental Phase No. 1 that the basic assumptions, which presumed each test condition to be independent and comparative, were incorrect. Interdependency between test conditions was indicated by unequal carryover effects between test conditions, by interactions between subjects and cycles and by interactions between subjects and days. These interactions were attributed to the progressive adaptation of the subjects to both the work situation and to the test conditions. Using physiological responses as comparison criteria statistical analysis was unsuccessful in determining differences between test conditions in the Experimental Phase No. 1, primarily because the

basic assumptions were incorrect. The experimental design for Experimental Phase No. 2 was expected to preclude carryover effects between test conditions and to prevent the onset of thermal shock upon removal of the headdress during exposures to the hot conditions. Acclimatization of the subjects to the work and the the environments was expected to continue. Therefore, the rate of acclimatization, which determines tho magnitude of the differences introduced by acclimatization, indescriminable from those differences attributable to the test conditions, would ascertain the soundness of any statistical evaluation.

Heart Rate and Oxygen Consumption

Although it was considered that statistical evaluation of the heart rate data was untenable and grave doubts existed with regard to the oxygen consumption data, it was considered advisable to attempt at least some indication of the sources responsible for the effects evident in the data. For ease of reading and for unity of text, the results will be presented by environmental conditions.

Cool Condition. For the majority of the test cycles Muller's (1953) Recovery Pulse Sum (RPS) was moasured with a planimeter from the heart rate curves following the procedure described in Experimental Phase No. 1. Where it was impossible to measure the area under the pulse curve, the area of the right triangle bounded by time and heart rato was calculated geometrically. Using the Wilcoxon Matched-Pair Signed-Rank test, no significant differences were found between test conditions, but a significant difference between the first (9/19) and the second (9/22) days of exposure was found. Tho RPS values were smaller on the second exposure to the cool condition regardless of the test conditions. This difference

indicates that the rate of adaptation of the subjects to the test conditions was greater than the effects introduced by the test conditions.

It was attempted to quantify the relationships between the maximum energy expenditure (MEE = rest O_2 plus net work O_2) and the RPS by using the Spearman rank correlation coefficient. No significant correlations were found between these physiological indices when they were grouped by either test conditions or exposure days. It was known that the metabolic data was somewhat unreliable because the recovery period extended past the six minutes during which O_2 consumption was measured, but during the second exposure to the cool condition the recovery for most of the work cycles occurred within the time the Recovery O_2 consumption was being measured. The absence of any significant correlation between these indices was contrary to the results found in Experimental Phase No. 1 and a doubt now arose with regard to the procedure used to calculate the RPS.

By having the single test condition throughout the exposure it was possible to observe that the modal resting level heart rate between work cycles declined as the exposure progressed. The resting heart rate at the start of a work cycle (P_i) was lower than the same value for the preceding cycle. As a result of this, two areas, labeled Difference A and Difference B in Figs. 21 through 24, became apparent. Muller (1953) indicated that the basic pulse rate (BPR) should be used as the baseline for calculating the RPS but when repeated work cycles occur, as in this experiment, the resting heart rate between work cycles may increase or decrease according to the severity of the environment and the time allowed for recovery between cycles. The area labeled Difference A quantifies the area obtainable when calculating the RPS by using either the BPR or the P_i and occurs when $P_i <$ BPR. The area labeled Difference B quantifies the same difference

EXPLANATION OF PLATE XVI

Fig. 21. Heart Rate vs. Exposure Time for Subject CHA with the headdress during the second of two exposures (9/22/66) to the Cool Condition of Experimental Phase No. 2.

Fig. 22. Heart Rate vs. Exposure Time for Subject CHA without the headdress during the first of two exposures (9/19/66) to the Cool Condition of Experimental Phase No. 2.

PLATE XVI

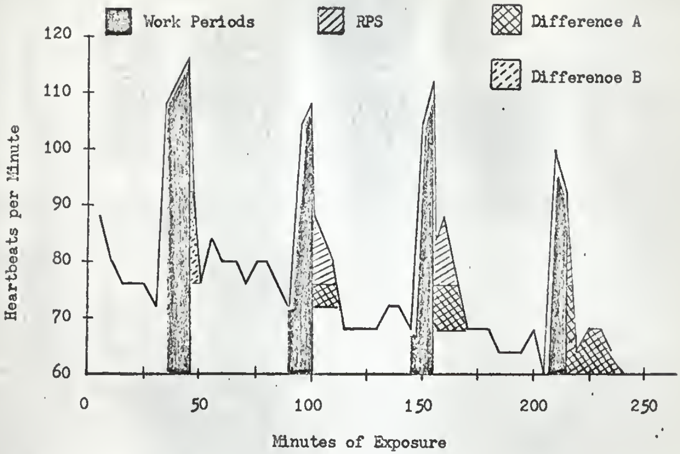

Fig. 21

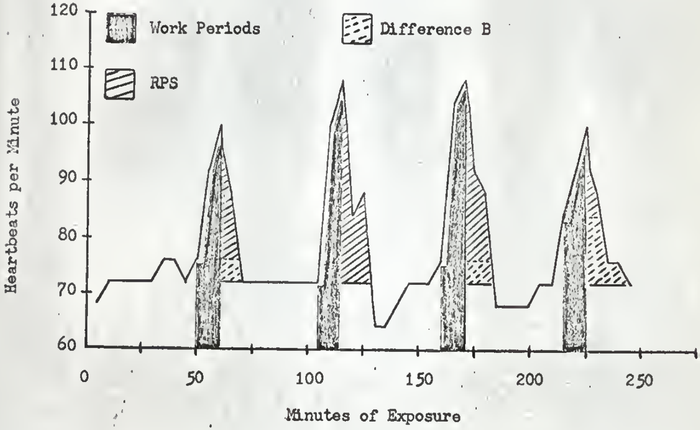

Fig. 22

EXPLANATION OF PLATE XVII

Fig. 23. Heart Rate vs. Exposure Time for Subject BAK with the headdress during first of two exposures (9/19/66) to the Cool Condition of Experimental Phase No. 2.

Fig. 24. Heart Rate vs. Exposure Time for Subject BAK without the headdress during second exposure (9/22/66) to the Cool Condition of Experimental Phase No. 2.

PLATE XVII

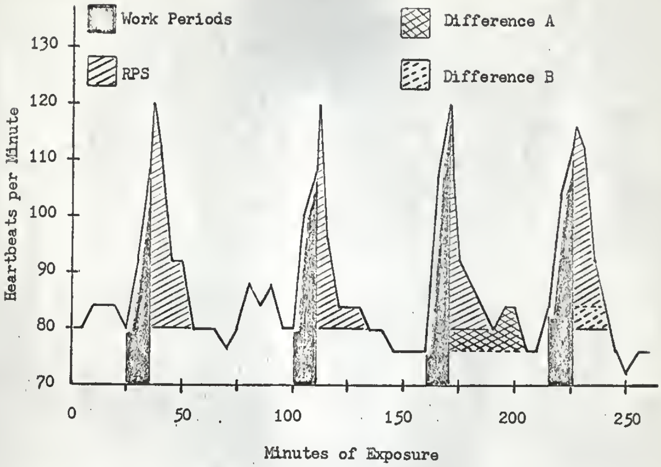

Fig. 23

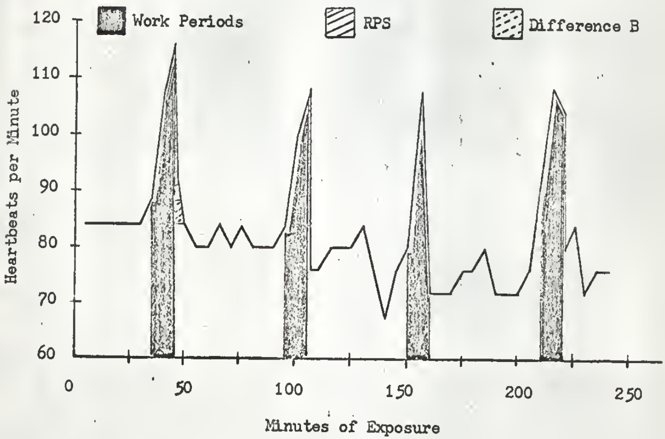

Fig. 24

and occurs when $P_i > BPR$. This situation may also occur when the pulse rate has not reached equilibrium for the environment prior to the start of a work cycle. Therefore, the calculation of the RPS by measuring the area under the pulse curve, as it has been done throughout this experiment, instead of counting the number of pulses needed to achieve recovery as Muller (1953) indicates in his study, may yield very misleading and inaccurate values for the RPS.

The heart rate rose immediately upon stopping work instead of exponentially declining on three of the sixteen work cycles that both subjects underwent in the cool condition. All three instances occurred during the first exposure of subject BAK while wearing the headdress. Based on the above, the physical fitness of the subject still appears to be the cause of this phenomena.

Hot Condition. With no base line from which to calculate the RPS during the exposures to this condition, a graphical display of the pulse curves was made to impress the reduced cardiac cost observed when the subjects were wearing the headdress. Figures 25 and 26 were constructed by superimposing the heart rate curves for a subject when exposed either with or without the headdress to this environmental condition.

Two very important factors, which point toward beneficial aspects of the headdress when worn in a hot-humid environment, were brought out:

1. Recovery after work. During the rest periods between work cycles the heart rate returned to near the BPR when the subject wore a headdress, which indicates that cardiac recovery was achieved prior to starting a new work cycle.

2. Maximum heart rate observed at the end of the work cycles. The maximum heart rates reached when wearing the headdress were lower than when without the headdress, primarily because recovery had been achieved prior to initiating a new work cycle and also because

EXPLANATION OF PLATE XVIII

Fig. 25. Heart Rate vs. Exposure Time for subject BAK with and without the headdress during two exposures (9/20/66 without headdress, 9/21/66 with headdress) to the Hot Conditions of Experimental Phase No. 2.

PLATE XVIII

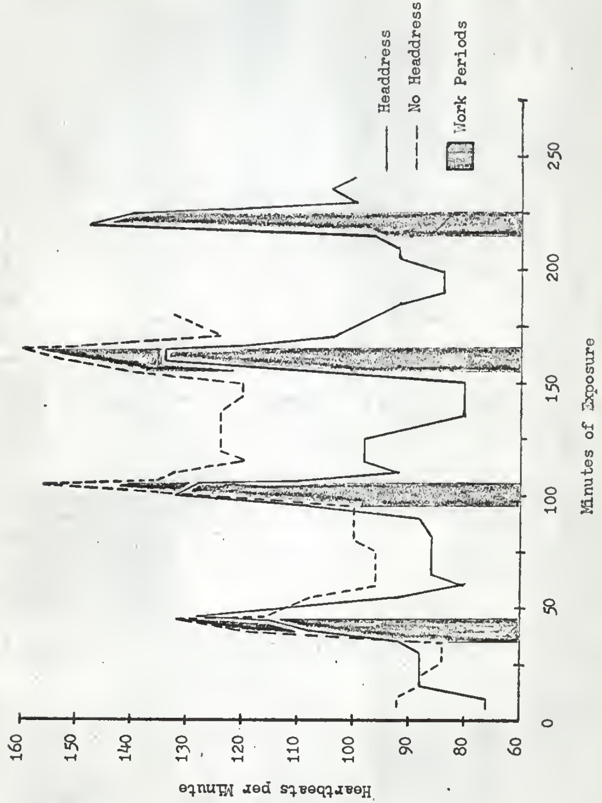

Fig. 25

EXPLANATION OF PLATE XIX

Fig. 26. Heart Rate vs. Exposure Time for subject CHA with and without the headdress during two exposures (9/20/66 with headdress, 9/21/66 without headdress) to the Hot Conditions of Experimental Phase No. 2.

PLATE XIX

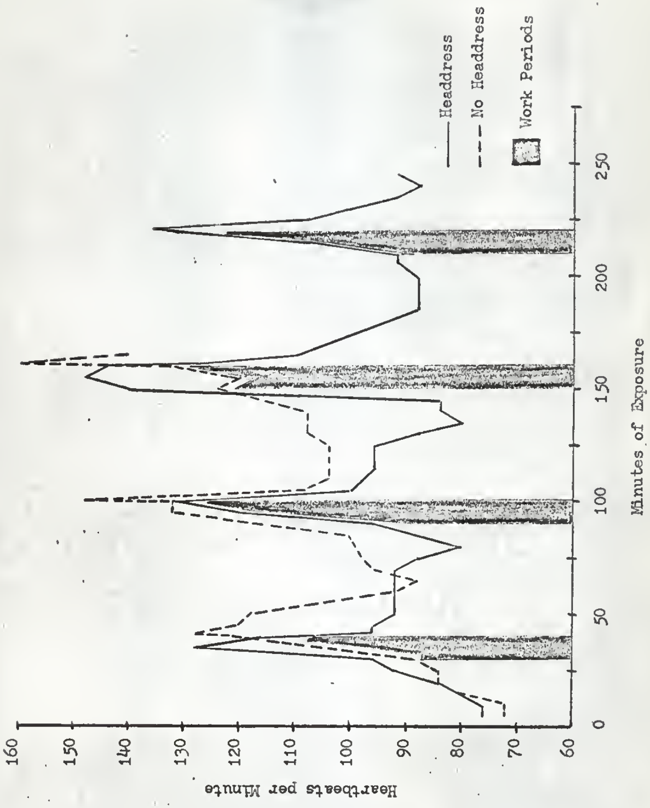

Fig. 26

> the oxygen consumption data, although somewhat unreliable, indicates higher maximum consumption rates (rest O_2 plus net work O_2) when wearing the headdress.

Muller (1953) ties the maximum energy expenditure (MEE) directly to recovery because the higher the MEE the quicker the recovery. Pembrey and Hale-White (1896) suggested faster rates of catabolic conversion at lower blood temperatures. Williams et al (1962) reported lower oxygen consumption for equal work rates at higher rectal temperatures. It appears as though oxygen consumption is regulated by internal temperature with "normal" consumption when internal temperature is within the thermoregulatory functional range. On the high side of the functional range, consumption decreases until internal temperature goes past a point where consumption increases sharply as reported by Winslow and Herrington (1949). With lower temperatures, consumption increases until another uncertain cut-off point is reached when a general slowdown of metabolic processes occurs as reported by Smith and Fay (1941). The average maximum oxygen consumption (rest O_2 plus net work O_2) values observed for the Cool no headdress (1.194 liters/minute), Cool headdress (1.212 liters/minute), and Hot headdress (1.205 liters/minute) test conditions in Experimental Phase No. 2 were almost equal. The value for the Hot no headdress condition (1.134 liters/minute) is considered the most unreliable because recovery was not achieved between cycles and the effect described by Brouha (1960) as the result of incomplete recovery augmenting the cardiac strain of succeeding work cycles occurred. Therefore, the high maximum oxygen consumption values, the recovery between work cycles and the lower maximum heart rates observed during this environmental condition indicate that the headdress provided sufficient conductive cooling to beneficially lower the "internal" temperature of the wearer.

The heart rate rose immediately upon stopping work only once in the

eight work cycles when the headdress was worn (the first work cycle of subject BAK) and all six times when it was not. Physical fitness alone can not be responsible for all of those occurrences, but something else possibly related to the MEE as a result of the internal temperature appears now as a factor.

Core, Skin and Head Temperatures

The same procedure described in the Experimental Phase No. 1 was used to obtain T_c, T_s and T_h for every five minutes of the test exposures. The averages of the four hour exposures will be referred to as $T_{\bar{c}}$, $T_{\bar{s}}$ and $T_{\bar{h}}$. The difference between the temperature recorded at the start and that recorded at the end of the exposure will be referred to as ΔT or as the change in a temperature index during exposure. T_c, T_s and T_h were plotted versus exposure time in order to evaluate the thermoregulatory behavior of each subject. Each environmental condition will be dealt with separately.

Cool Condition. During the exposure to the cool condition without the headdress it was observed that the core temperature was the highest and the skin temperature the lowest. The head temperature was in between the core and skin temperatures. For CHA, $T_{\bar{s}}$ was 5.2° C. (9.4° F.) lower than $T_{\bar{c}}$ and the $T_{\bar{h}}$ was 3.0° C. (5.4° F.) lower than $T_{\bar{c}}$; thus $T_{\bar{h}}$ was 2.2° C. (4.0° F.) above $T_{\bar{s}}$. ΔT_s for CHA was +0.7° C. (+1.2° F.) for the four hour exposure, while ΔT_c was +0.1° C. (+0.2° F.). (See Fig. 27.) For BAK, $T_{\bar{s}}$ was 4.1° C. (7.4° F.) lower than $T_{\bar{c}}$ and the $T_{\bar{h}}$ was 3.0° C. (5.4° F.) lower than $T_{\bar{c}}$; thus $T_{\bar{h}}$ was 1.1° C. (2.0° F.) above $T_{\bar{s}}$. ΔT_s for BAK was -1.5° C. (-2.7° F.) for the four hour exposure with no change in T_c. The gradient between $T_{\bar{c}}$ and $T_{\bar{h}}$ was 3° C. (5.4° F.) for both subjects, but the gradient between $T_{\bar{h}}$ and $T_{\bar{s}}$ was 2.2°C. (4.0° F.) for CHA and only 1.1° C.

(2.0° F.) for BAK. The downward trend of T_s ($\Delta T_{s_{BAK}} = -1.5°$ C.) during the exposure coupled to the smaller gradient between $T_{\bar{h}}$ and $T_{\bar{s}}$ shows evidence of evaporative cooling for BAK in the cool environment.

The T_h and T_s curves for CHA formed a peak during or briefly after each work cycle (see Fig. 27) while the same curves for BAK decreased sharply during the equivalent periods. Guyton (1966) suggested that sudomotor activity ensues as a result of the sensor-effector organs reaction to a rise in internal temperature. Blockley (1965) reported that the skin temperature at the sweating threshold is inversely proportional to the metabolic rate. From the metabolic data available it was determined that during this test condition (Cool no headdress) BAK's average net work oxygen consumption was 0.93 liters/minute while CHA's was 0.84 liters/minute. These figures indicate that the work rate was more difficult for BAK and consequently he generated a greater amount of heat during the work cycles. Although T_c did not show any sharp changes in the "internal" temperature of the subjects during the work cycles, the decrease observed in the T_s and T_h curves during the work cycles of subject BAK indicate evaporative cooling as a result of sudomotor activity triggered by a rise in internal temperature. Once more the disassociation between the observed T_c and the internal temperature which triggers the sensor-effector mechanisms of thermoregulation was apparent.

During the exposures to the cool condition while wearing the headdress it was observed that the core temperature was the highest and the head temperature the lowest. The skin temperature was in between the head and core temperatures (see Fig. 28). For subject BAK, $T_{\bar{h}}$ was 5.1° C. (9.2° F.) below the $T_{\bar{c}}$ and the $T_{\bar{s}}$ was 4.0° C. (7.2° F.) lower than $T_{\bar{c}}$; thus $T_{\bar{s}}$ is 1.1° C. (2° F.) higher than $T_{\bar{h}}$. For subject CHA $T_{\bar{h}}$ was 5.4° C.

EXPLANATION OF PLATE XX

Fig. 27. Core, Skin and Head Temperatures (T_c, T_s and T_h respectively) observed on subject CHA while without the headdress during the first exposure (9/19) to the Cool condition of Experimental Phase No. 2.

Fig. 28. Core, Skin and Head Temperatures (T_c, T_s and T_h respectively) observed on subject CHA while wearing the headdress during the second exposure (9/22) to the Cool Condition of Experimental Phase No. 2.

PLATE XX

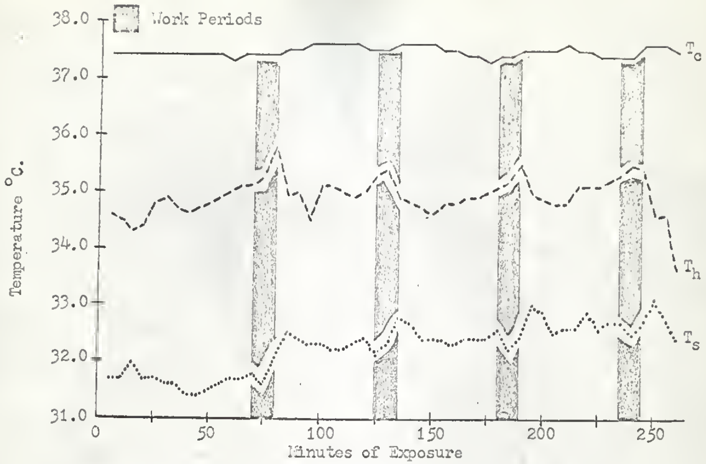

Fig. 27

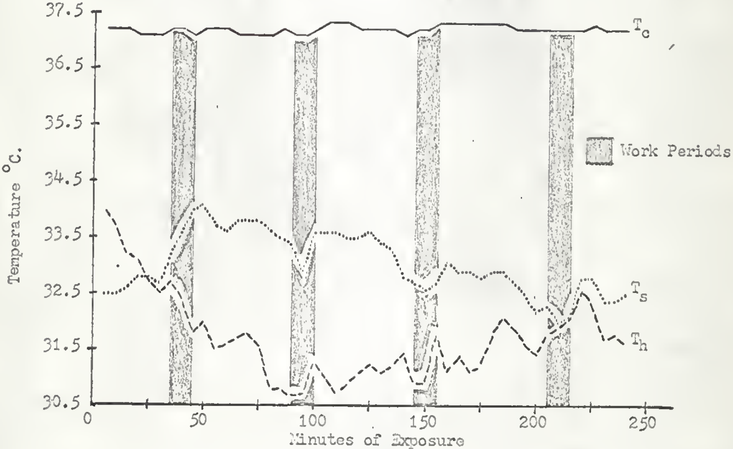

Fig. 28

(9.7° F.) below the $T_{\bar{c}}$ and the $T_{\bar{s}}$ was 3.9° C. (7.0° F.) lower than $T_{\bar{c}}$; thus $T_{\bar{s}}$ is 1.5° C. (2.7° F.) higher than the $T_{\bar{h}}$. The gradient ($T_{\bar{c}}$ - $T_{\bar{s}}$) was 4° C. (7.2° F.) for both subjects. This gradient was larger with the headdress (4° C.) than without the headdress (3° C.). The changes observed as ΔT_s and ΔT_c during the four hour exposure with the headdress were negligible when compared to those observed when without the headdress, but the difference between T_s at the start and T_s at the end of the exposure without the headdress does not describe what happened. For instance, during the first 50 minutes of the exposure of subject CHA with the headdress, T_s increased 1.6° C. (2.9° F.) while T_c remained steady. (See Fig. 28.) During the same period T_h decreased 2° C. (3.6° F.). The peak of this rise was the highest T_s observed during the four hour exposure since during the remaining 195 minutes T_s decreased until it returned to the initial level. When this rise in T_s occurred both the temperature of the radiating surfaces of the room and the globe thermometer temperature were lower than T_s. In conjunction with this, the vapor pressure of the air was lower than the vapor pressure of the skin. With the environment acquiescent to convection, radiation and evaporative losses in addition to the conductive cooling of the headdress, T_s increased. This rise in T_s seems to indicate that heat storage occurred, possibly as a result of subcutaneous vasoconstriction triggered by the lower head temperature.

When the highest skin temperatures after a work cycle were plotted versus the concurrent T_c, as it was done in Experimental Phase No. 1 to indicate the sudo-motor activity thresholds of the subjects, the variability between subjects when without the headdress was apparent. When the headdress was worn the variability between subjects was reduced as it had occurred in Experimental Phase No. 1. No statements regarding sudomotor

thresholds can be made from the curves in Fig. 29 except that the concurrent T_c's were lower when wearing the headdress.

To summarize, it appears that in the cool condition the headdress increases the temperature gradient between T_s and T_c, is capable of triggering subcutaneous vasoconstriction to prevent heat losses in a cool environment and it reduces the variability between the subject's sudomotor thresholds.

Hot Condition. The exposure to this condition without the headdress was terminated when ΔT_c reached 1.1° C. (2.0° F.). For subject BAK the T_h curve was in between the T_c and T_s curves. BAK was able to maintain a 1° C. (1.8° F.) gradient between T_c and T_s (see Fig. 31) and reached the tolerance limit (ΔT_c = 1.1° C.) in 170 minutes after completing three work cycles. For subject CHA the T_s curve was in between the T_c and T_h curves and T_s exceeded T_c after the work cycles. CHA was unable to maintain a gradient between T_c and T_s greater than 0.5° C. (0.9° F.) but reached the tolerance limit in 175 minutes after completing three work cycles.

Heat stress in hot-humid environments is due primarily to the restrictions imposed by the environment on the evaporation of sweat. Heat gains from metabolism, convection and radiation must either be dissipated through evaporation or stored. Although BAK was able to dissipate a greater amount of heat through evaporation as indicated by the gradient between T_c and T_s, heat storage progressively increased, possibly because BAK had a higher metabolic heat production than CHA, until in about three hours it exceeded the tolerance limit. The metabolic data for Hot no headdress condition, although inaccurate, at least indicates the direction of the differences between subjects. The average resting O_2 consumption of both

EXPLANATION OF PLATE XXI

FIG. 29. Graph showing the shifting of the sudomotor activity threshold when the headdress is worn, constructed by plotting the highest T_s observed after a work cycle versus the concurrent T_c.

FIG. 30 A plot of the core temperatures observed on subject CHA during the two exposures to the Hot Condition in Experimental Phase No. 2.

PLATE XXI

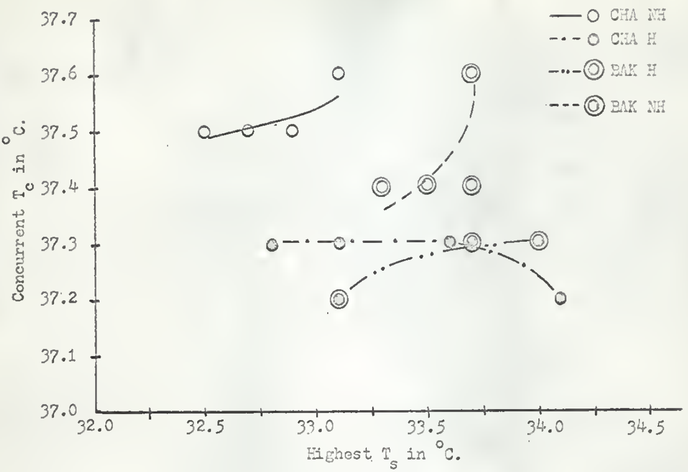

Fig. 29

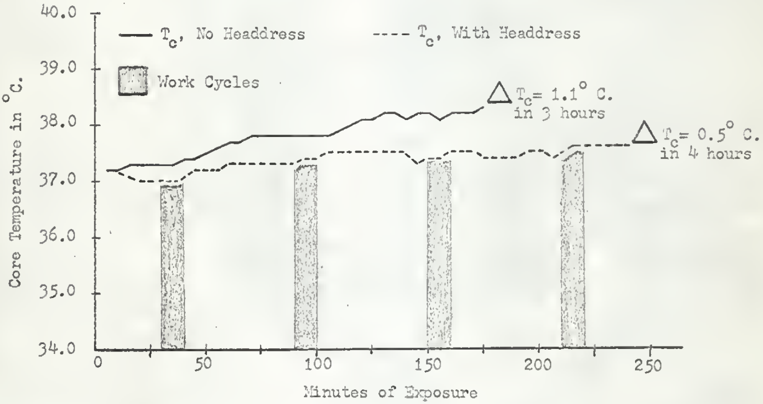

Fig. 30

EXPLANATION OF PLATE XXII

Fig. 31. Core, Skin and Head Temperatures (T_c, T_s and T_h respectively) observed on subject BAK when without the headdress during the first of two exposures to the Hot Condition (9/20) of Experimental Phase No. 2.

Fig. 32. Core, Skin, and Head Temperatures (T_c, T_s and T_h respectively) observed on subject BAK when wearing the headdress during the second of two exposures to the Hot Condition (9/20) of Experimental Phase No. 2.

PLATE XXII

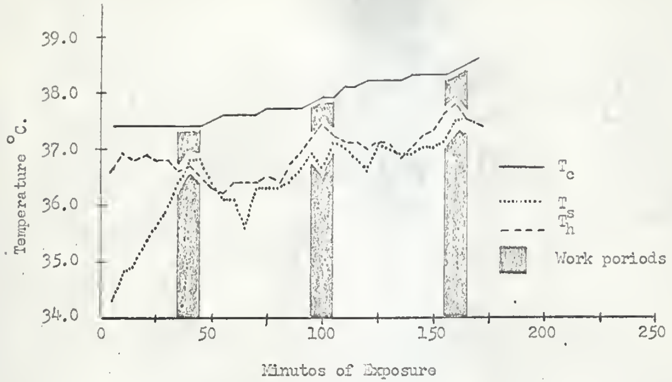

Fig. 31

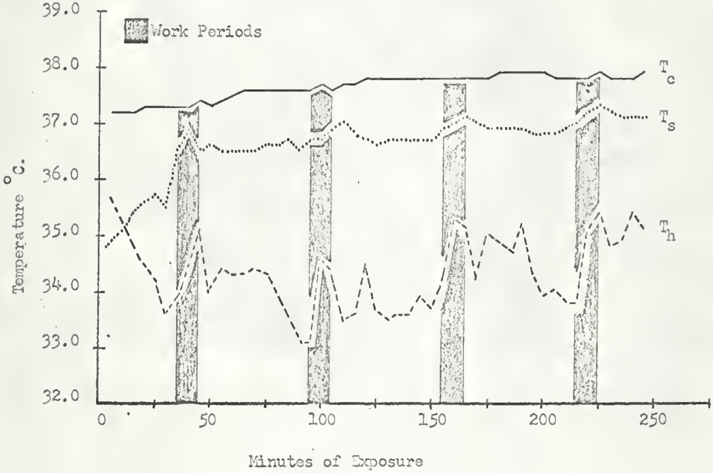

Fig. 32.

subjects was about equal at 0.33 liters per minute, but the average net work O_2 consumption was 0.83 liters per minute for BAK and 0.77 liters per minute for CHA. The difference between the average net work metabolic rates appears to be small, but to dissipate the equivalent heat production of 0.06 liters of O_2 per minute it is necessary to evaporate 2.8 grams of sweat per minute. Sweat was evident on the skin surface during all of the exposure. Considerable sweat runoff occurred during the exposure without the headdress.

When the headdress was worn during the exposure to the hot condition, the subjects were able to finish the scheduled four work cycles without any indications of thermal stress. ΔT_c for BAK was +0.7° C. (+1.3° F.) and for CHA it was +0.5° C. (0.9° F.). (See Fig. 30.) The skin temperature curve of both subjects was between the T_c and the T_h curves. (See Fig. 32.) The gradient between T_c and T_s was dependent on the T_h which in turn was subordinate to the temperature of the water circulating in the headdress. T_h for BAK fluctuated between 33.1° C. (91.6° F.) and 35.4° C. (95.7° F.) while for CHA T_h fluctuated between 29.7° C. (85.5° F.) and 33.2° C. (91.8° F.). There were no provisions for maintaining a constant water temperature circulating in the headdress. The criteria for adding ice to the reservoir was that ice should be floating on the water at all times.

The gradient between T_c and T_s indicates that evaporative cooling was taking place during the exposure to the Hot headdress condition. Only during and briefly after a work cycle were sweat beads evident on the skin surface of the subjects when they were wearing the headdress. Weight loss data indicates sweating, but the absence of sweat runoff points toward efficient use of the sweat for cooling purposes. The metabolic data for the Hot headdress condition shows that O_2 consumption was as high during

this test condition as the exposures to the cool condition with or without the headdress; consequently heat production with the headdress in the Hot condition was higher than without the headdress. The combination of conductive cooling at the head area and evaporative cooling on the rest of the body was able to prevent excessive heat storage and allow for the completion of four work cycles.

To summarize, during the exposure to the hot condition with the headdress the subjects produced more metabolic heat than without the headdress. There was no sweat runoff indicating that possibly only the skin sensor effector organs were controlling sudomotor activity. Only during and briefly after exercise did sweat beads become evident on the subjects' skin probably due to further sweating prompted by the rise in internal temperature. The duration of the exposure was extended one work cycle longer than when working in the same environment without the headdress.

Weight Losses

The subjects were weighed before and after the exposures. For comparison purposes the net weight loss of each test condition was reduced so that it could be expressed in units of time and body area. Table 12 shows the weight losses observed during Experimental Phase No. 2. The weight loss with the headdress was between 37 to 46 percent of the weight loss without the headdress. This indicates inhibition of the sweating mechanisms by the headdress. In the hot condition the subjects when wearing the headdress were able to work longer with less sweat loss per time unit. Robinson (1963) states that dehydration and its consequent reduction of plasma volume increases the circulatory strain and reduces the tolerance of men to heat stress. Pitts, Johnson and Consolazio (1944) found that water

Table 12. Weight losses observed during the test condition of Experimental Phase No. 2.

	Hot Condition			
	Headdress		No Headdress	
	BAK	CHA	BAK	CHA
Weight loss in Kg.	1.83	1.40	2.75	2.76
Weight loss in % of body weight	2.1	1.6	3.2	3.2
Exposure time in minutes	245	240	170	175
Weight loss in $gr./min./m^2$ of body area	3.70	3.05	8.00	8.25
	Cool Condition			
	Headdress		No Headdress	
	BAK	CHA	BAK	CHA
Weight loss in Kg.	0.69	0.35	1.58	0.80
Weight loss in % of body weight	0.8	0.4	1.8	0.9
Exposure time in minutes	290	240	240	260
Weight loss in $gr./min./m^2$ of body area	1.17	0.76	3.27	1.61

deficits as low as 1 to 2 percent of body weight caused measurable evidences of increased circulatory strain. The strain under constant conditions of metabolic rate and heat stress increased linearly with further increments in water deficit until "dehydration exhaustion" occurred. In the cool environment with or without the headdress both subjects averaged weight losses of less than 2%. In the hot environment without the headdress, the average weight loss of the subjects was 3.2% of the body weight and with

the headdress it was under 2%. This can be considered as evidence of less circulatory strain when wearing the headdress.

Subjective Sensations

Both subjects differed in their sensation of the test conditions and their opinions reflected their physiological behavior. Table 13 shows their

Table 13. Subjective sensation of test conditions voiced by subjects.

Condition	Cycle No.	Subject BAK	Subject CHA
Cool, With Headdress	1	Comfortable	Comfortably Cool
	2	"	" "
	3	"	" "
	4	"	Too Cool
Cool, Without Headdress	1	Comfortable	Comfortable
	2	"	"
	3	Comfortably Cool	"
	4	" "	"
Hot, With Headdress	1	Comfortable	Comfortably Warm
	2	Very Comfortable	Comfortable
	3	" "	"
	4	" "	"
Hot, Without Headdress	1	Too Warm	Too Warm
	2	" "	" "
	3	" "	" "
	4	-----	-----

voiced opinions of the test conditions. In the hot condition the headdress seemed to affect BAK to a higher degree than it influenced CHA, but the reverse occurred in the cool condition.

Experimental Phase No. 2 - Discussion

The objectives of the investigation were fulfilled during the second experimental phase. The primary objective was to find out if the exposure time of a person in a hot-humid environment could be extended by wearing the headdress. During the exposure to the hot environment without the headdress, both subjects exceeded the tolerance limit ($\Delta T_{c_{limit}} = +1.1^{\circ}$ C.) in less than three hours and were taken out of the test room. When the subjects wore the headdress they completed the four hour scheduled exposure without any undue heat stress ($\Delta T_{c_{ave.}} = +0.6^{\circ}$ C.).

The second objective of the investigation was to observe if the blood was actually cooled by the headdress. Several occurrences indicate that the headdress did cool the blood that bathes the thermoregulatory controls. It was observed that during the exposures to the cool condition, subcutaneous vasoconstriction was triggered to prevent excessive heat losses to the environment. Heat storage, manifested by a rise of T_c or T_s in the cool environment while wearing the headdress, was an indication of this vasoconstriction. Other indications that were inferred to be evidence of cooling the blood were the metabolic rates observed during the exposure to the hot condition with the headdress. If the internal blood temperature is considered as a determinant of metabolic rates, then the similarity of the rates observed in the Hot headdress condition with both test conditions in the cool environment would indicate similar "internal" temperatures during the Cool headdress, Cool no headdress and Hot headdress test condi-

tions. The reader may wonder why there was little difference between the metabolic rates observed for the Cool headdress and those observed for the Cool no headdress condition. The means used to maintain thermal balance by the subjects when wearing the headdress in the cool condition were different than the means used when they were without the headdress. With the headdress they had to cope with conductive cooling by the headdress in addition to the radiation, conduction and evaporation losses to the environment, and evaporative loss was less as evident by tho lower weight loss observed during tho cool headdress condition. When not wearing the headdress they maintained thermal balance by larger evaporative losses in addition to the radiation and convection heat losses to the environment. These internal adjustments were sufficient to preclude major changes in heat production in the cool environment.

The third objective of the investigation was to determine any undue side effects resulting from the manipulation of the subjects' thermoregulatory mechanisms. In the Experimental Phase No. 1 the onset of thermal shock as a result of removing the headdress in the hot environment was attributed to poor experimental design. This occurrence cautioned against this practice and during the Experimental Phase No. 2 care was exercised that the subject should leave the hot environment immediately after the headdress was removed. Core temperatures decreased exponentially to the BCT without any difficulties as evidence of no undue side effects from wearing the headdress during four consecutive cycles in the hot environments. Beneficial aspects of wearing the headdress in the hot environment were indicated by the higher metabolic rates, which speeded recovery between work cycles, and by lower weight losses, which decreased circulatory strain and prevented dehydration exhaustion.

In the Experimental Phase No. 2 the exposure time was increased, there were positive indications of lowering the blood temperature and no apparent undue side effects occurred as a result of wearing the headdress in a hot-humid environment. Further study of conductive cooling at the head should be undertaken to determine the heat exchanges via conductive cooling of the head and the other heat losses to the environment via radiation, conduction and evaporation. The differences obtained between these various modes of heat transfer would be used to determine the relative efficiencies of the thermoregulatory processes in hot-humid environments. The optimum operating temperature for the headdress has to be determined. It is suspected that the temperature of the water in the headdress was too low throughout the study, which may have resulted in vasoconstriction of the head surface with associated reduction in heat flow from the blood to the headdress. With reference to a full-body (excluding the head area) conductive cooling suits, Webb (1967) states that overcooling results in subcutaneous vasoconstriction, sensations of chilling and even possible muscle cramps. In full body conductive cooling suits, as well as with the headdress, the matter of control of cooling may be critical. Overcooling with the headdress could have been responsible for the onset of thermal shock observed in Experimental Phase No. 1. It is important that the temperature of the liquid in the headdress be variable and controlled by either the wearer using his subjective sensation as criterion or by a servo mechanism using the head or other temperature for feedback. According to Webb (1967) the need for heat removal is not constant and varies throughout an exposure to heat altered environments being greatest during and after activity. The rate and duration of activity determines the heat production, in excess of basal heat production, which must be removed to prevent heat

storage. This exploratory study in the physiological behavior of subjects in hot-humid environments with conductive cooling capability at the head has indicated the potential of blood cooling as a means of preventing physiological stresses and of assisting the thermoregulatory mechanisms in altered environments.

SUMMARY

Two series of experiments using two male unacclimatized paid student subjects were conducted at the Kansas State University - American Society of Heating, Refrigerating and Air Conditioning Engineers Institute of Environmental Research Test Chamber to investigate the physiological effects of a water cooled headdress on man when exposed to both a comfortable and to a heat stress environment. The comfortable environment consisted of $T_{A_{db}} = 24.4^{\circ}$ C. (76° F.), $T_{A_{wb}} = 17.4^{\circ}$ C. (63.4° F.), RH = 50%, $T_W = 31.6^{\circ}$ C. (89.1° F.) in still air. The heat stress environment consisted of $T_{A_{db}} = 37.8^{\circ}$ C. (100° F.), $T_{A_{wb}} = 32.6^{\circ}$ C. (90.7° F.), RH = 70%, $T_W = 33.3^{\circ}$ C. (92° F.) in still air. The subjects rested sitting during 50 minutes and pedalled a bicycle ergometer at a work output rate of 0.1 hp @ 40 rpm for ten minutes during each hour of a four hour exposure. In the first experimental phase each subject was exposed twice to each environment following either an ABBA or a BAAB sequence of one hour test conditions during the four hour exposures. In the second phase each subject experienced two four hour exposures to each environment, one with the headdress and one without it.

The objectives of the investigation were to find if man's exposure to a hot-humid environment could be extended by wearing the headdress, to find evidence that man's blood was cooled by the headdress and to observe any side effects resulting from the manipulation of his thermoregulatory

mechanisms. Measurements of heart rate, oxygen consumption, core, skin and head temperatures, weight loss and subjective sensations were used as criteria to compare the physiological behavior of the subjects when they were exposed to either environment with or without the headdress. Variability and differences between subjects, such as fitness and somatype, as well as the adjustment processes which resulted in interactions between subjects and test cycles and between subjects and test days made statistical differentiation between test conditions untenable.

Evidence that wearing the headdress inhibited sweating, that the threshold of sudomotor activity shifted and that subcutaneous vasoconstriction was triggered to reduce heat losses was found during the exposures to the comfortable environment. By these processes the subjects were able to maintain thermal balance when wearing the headdress without increasing metabolic heat production.

Fifty-eight percent less weight loss per unit of body area per minute of exposure indicated reduced circulatory strain when wearing the headdress in the heat stress environment. Reduced cardiac strain was indicated by complete cardiac recovery between work cycles and also by lower maximum heart rates observed during the work cycles, possibly as a result of the higher metabolic rates observed when the headdress was worn in the hot environment. The headdress assisted the subjects to complete the scheduled four hour exposure to the hot environment because when exposed without the headdress the test had to be discontinued after three hours when the subjects' core temperature had reached 1.1° C. (2° F.) above the basic core temperature. The removal of the headdress in the hot environment without removing the man from the environment prompted an onset of

thermal shock. If the headdress was removed and the man removed immediately afterwards from the environment no side effects occurred.

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THE PHYSIOLOGICAL EFFECT OF A WATER COOLED HEADDRESS IN A HEAT STRESS ENVIRONMENT

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Two experiments using two male unacclimatized paid student subjects were conducted to investigate the physiological effects of a water cooled headdress on man when exposed to two environmental conditions. The comfortable environment consisted of $T_{A_{db}} = 24.4^\circ$ C. (76° F.), $T_{A_{wb}} = 17.4^\circ$ C. (63.4° F.), RH = 50%, $T_W = 31.6^\circ$ C. (89.1° F.) in still air. The heat stress environment consisted of $T_{A_{db}} = 37.8^\circ$ C. (100° F.), $T_{A_{wb}} = 32.6^\circ$ C. (90.7° F.), RH = 70%, $T_W = 33.3^\circ$ C. (92.0° F.) in still air. The subjects rested sitting during 50 minutes and pedalled a bicycle ergometer at a work output rate of 0.1 hp @ 40 rpm for ten minutes during each hour of a four hour exposure.

In the comfertable environment the headdress inhibited sweating, shifted the threshold of sudomotor activity and triggered subcutaneous vasoconstriction to reduce heat losses so that the subjects were able to maintain thermal balance without increasing metabolic heat production.

In the heat stress environment, the headdress inhibited sweating, which is especially advantageous because it reduces circulatory strain. The headdress reduced cardiac strain as indicated by near complete cardiac recovery between work cycles and by lower maximum heart rates observed during the work cycles (possibly as a result of the higher metabolic rates observed when the headdress was worn in the hot environment.) With the headdress both subjects completed the scheduled four hour exposures; without the headdress the test had to be discontinued after three hours because the subjects' core temperature had risen 1.1° C. (2° F.). Removing the headdress in the hot environment without removing the man from the environment prompted an onset of thermal shock, but if the man was removed immediately afterwards from the environment no side effects occurred.